PCCC-2

Novel Absorber Intercooling Configurations

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Overview

- Modeling Framework (Aspen Plus®)
- Intercooling Configuration Comparison Study
  - In-and-Out vs. Recycle Intercooling
  - Results
- Conclusions

Modeling Framework: Rate Based Absorber

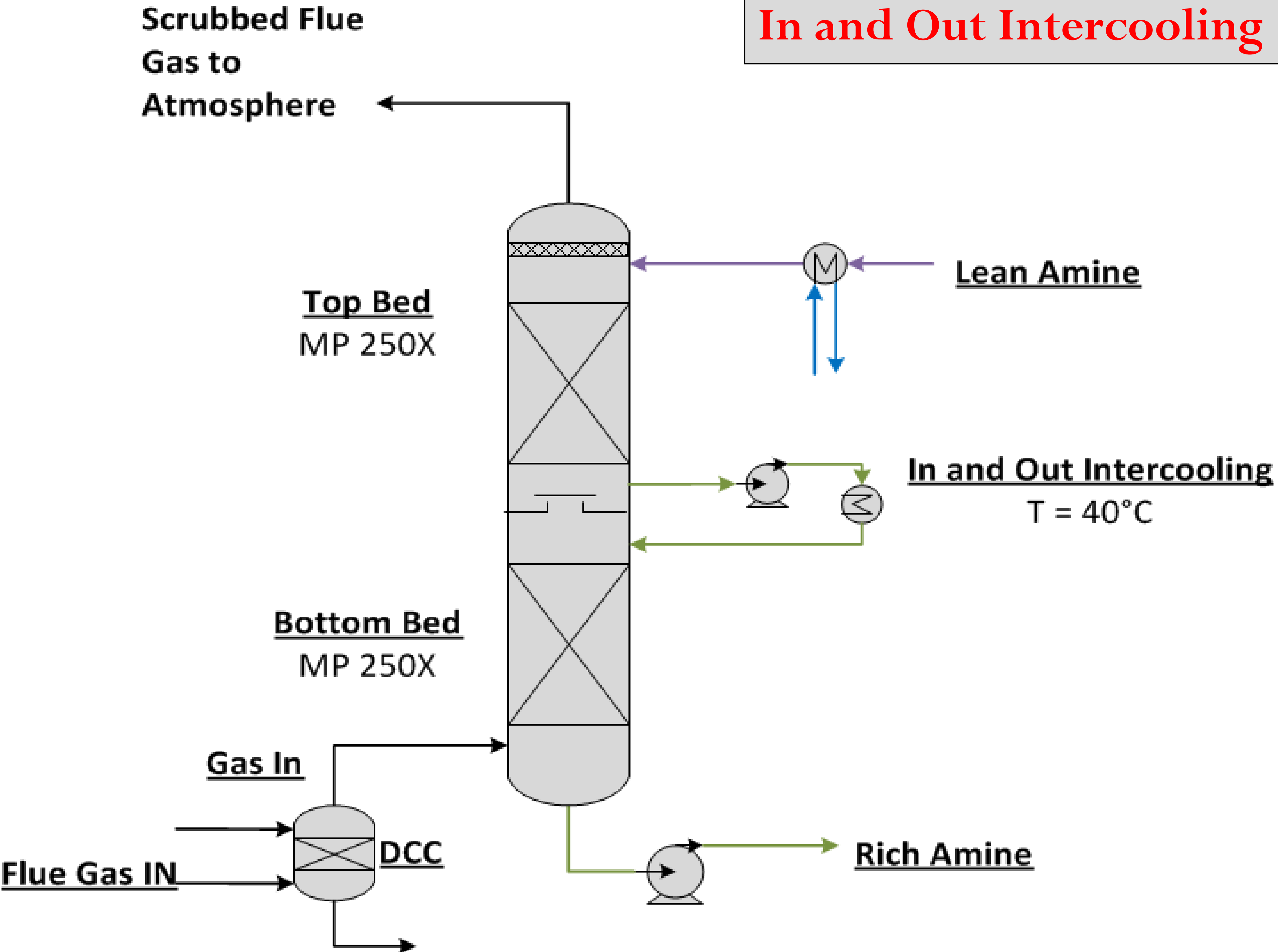
- Solvent Model : Thermodynamic and Kinetic PZ Model ("Independence", Frailie 2012, Aspen Plus®)
  1. **Thermo:** e-NRTL with regressed model parameters to fit experimental data (amine volatility, VLE, heat capacity, speciation/NMR)
  2. **Kinetics/Mass Transfer**: Regress rate constant and diffusion coefficient parameters using wetted wall column data
- Packing Mass Transfer Model (Tsai, Wang)
  1. Regress pilot scale air-water column data for variety of packing and hydraulic conditions
  - $k_L = f(u_L/a_p$, packing geometry, $\mu)$
  - $k_g = f(u_G/a_p$, packing geometry$)$
  - $a_e = f(u_L/a_p, \rho_L, \sigma)$

- Aspen Plus® RateSep

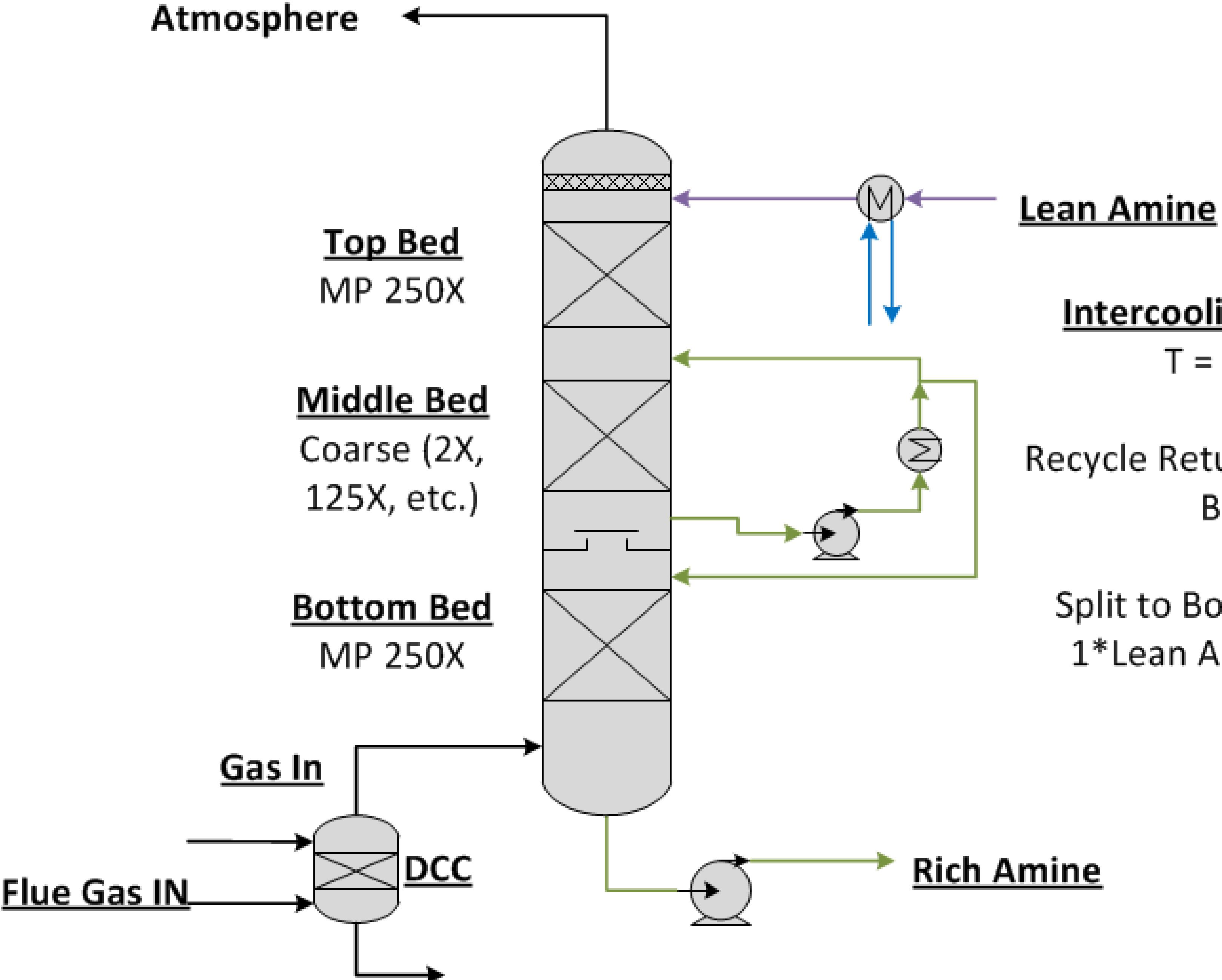
Intercooling Comparison Study

- Comparison of Intercooling Configurations
  - NGCC (4% CO_2)
    - 8m PZ solvent
    - LLDG = 0.25 mols CO_2/mols alkalinity
    - 90% CO_2 Removal
  - 4 Configurations
    - No Intercooling (Baseline)
    - In and Out Intercooling
    - Recycle with Bypass (Cooled solvent sent to section below)
    - Isothermal @40°C (Ideal)
  - Compare Packing Requirement and Rich Loading/Solvent Rate (proxy for energy performance)

In and Out Intercooling



Recycle Intercooling with Bypass



Scrubbed Flue
Gas to
Atmosphere

Lean Amine

Top Bed
MP 250X

Middle Bed
Coarse (2X,
125X, etc.)

Bottom Bed
MP 250X

Gas In

DCC

Flue Gas IN

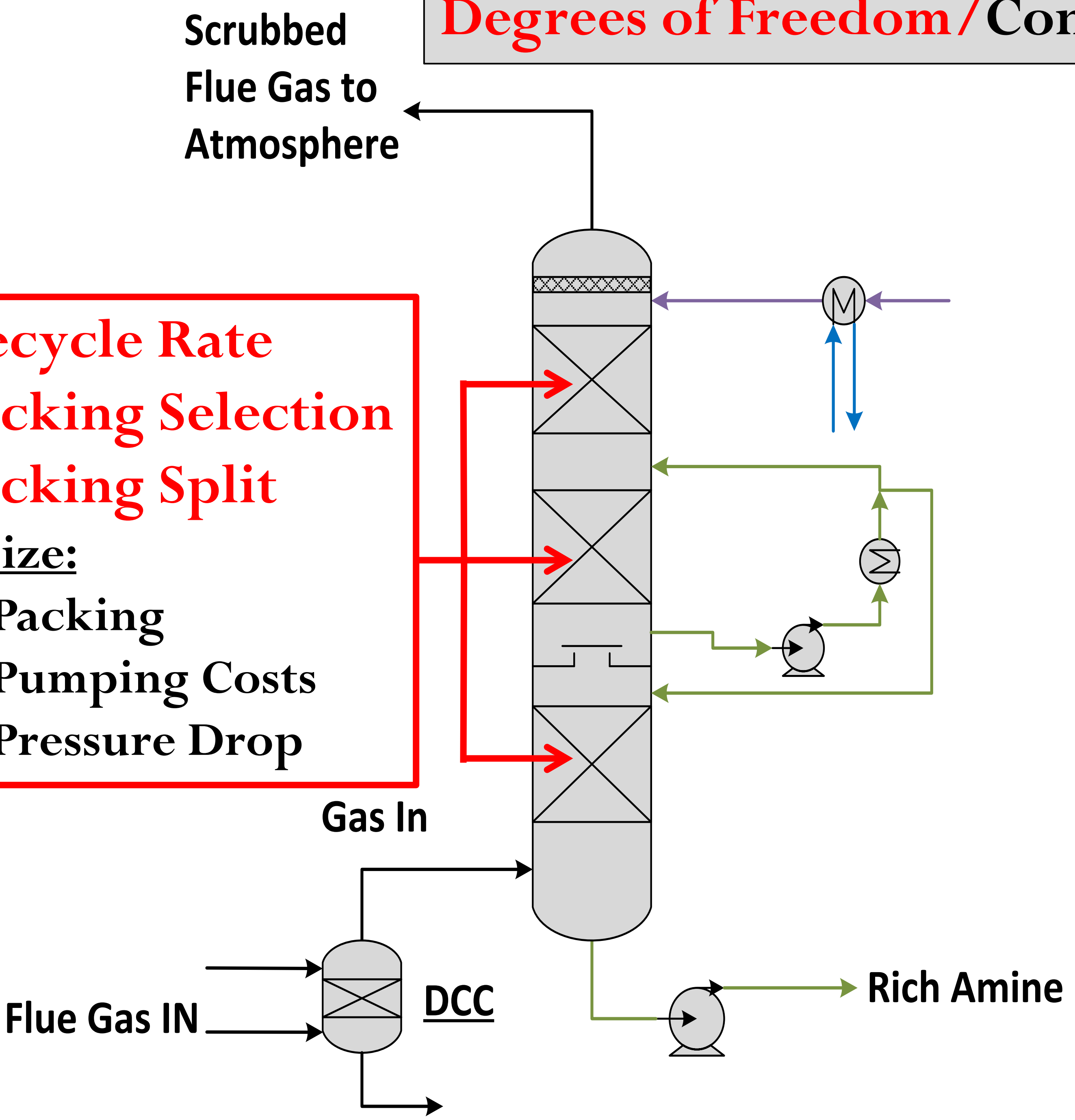
Rich Amine

Intercooling Recycle
T = 40°C

Recycle Return to Middle
Bed

Split to Bottom Bed =
1*Lean Amine Feed

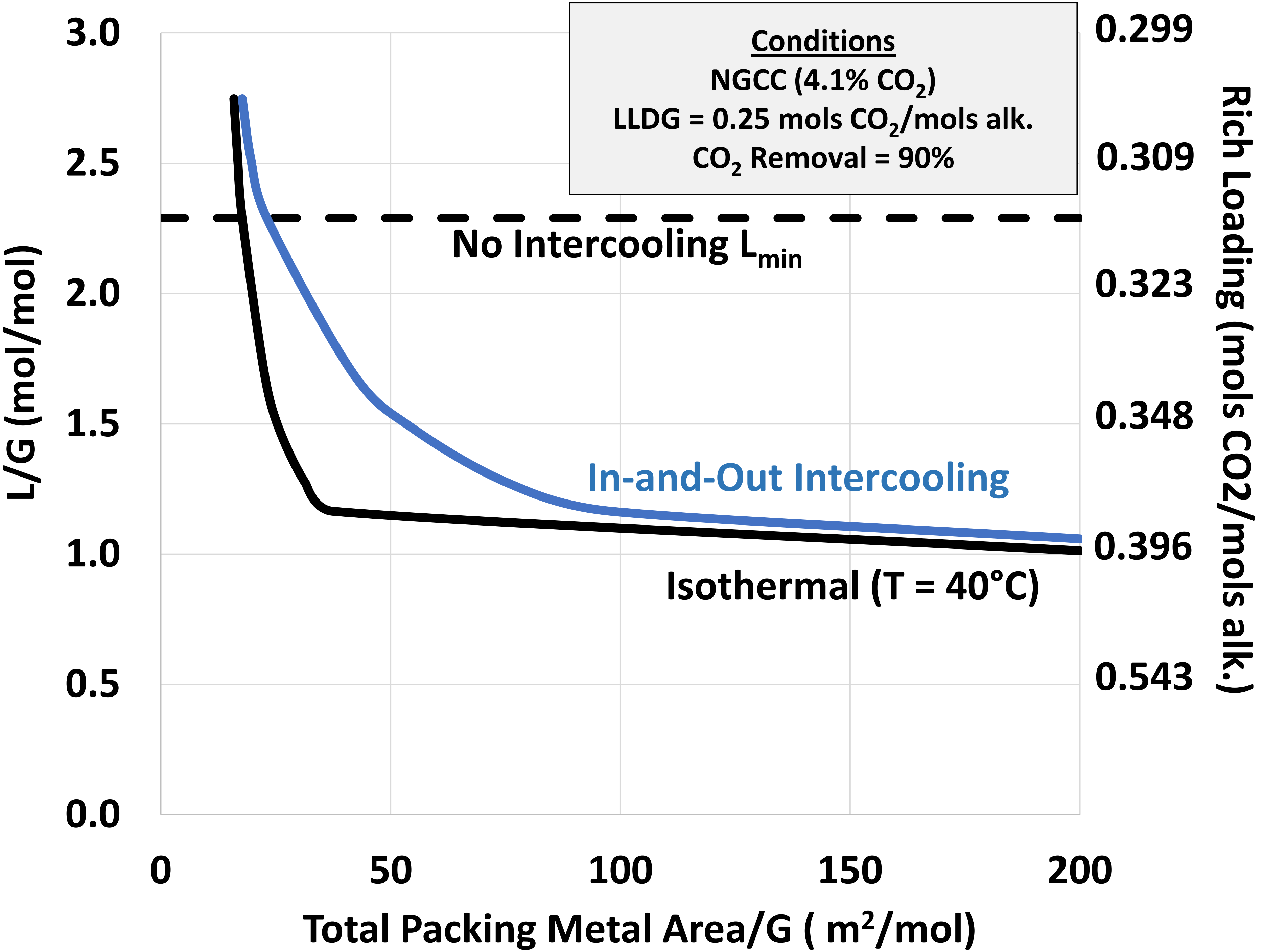
Degrees of Freedom/Constraints

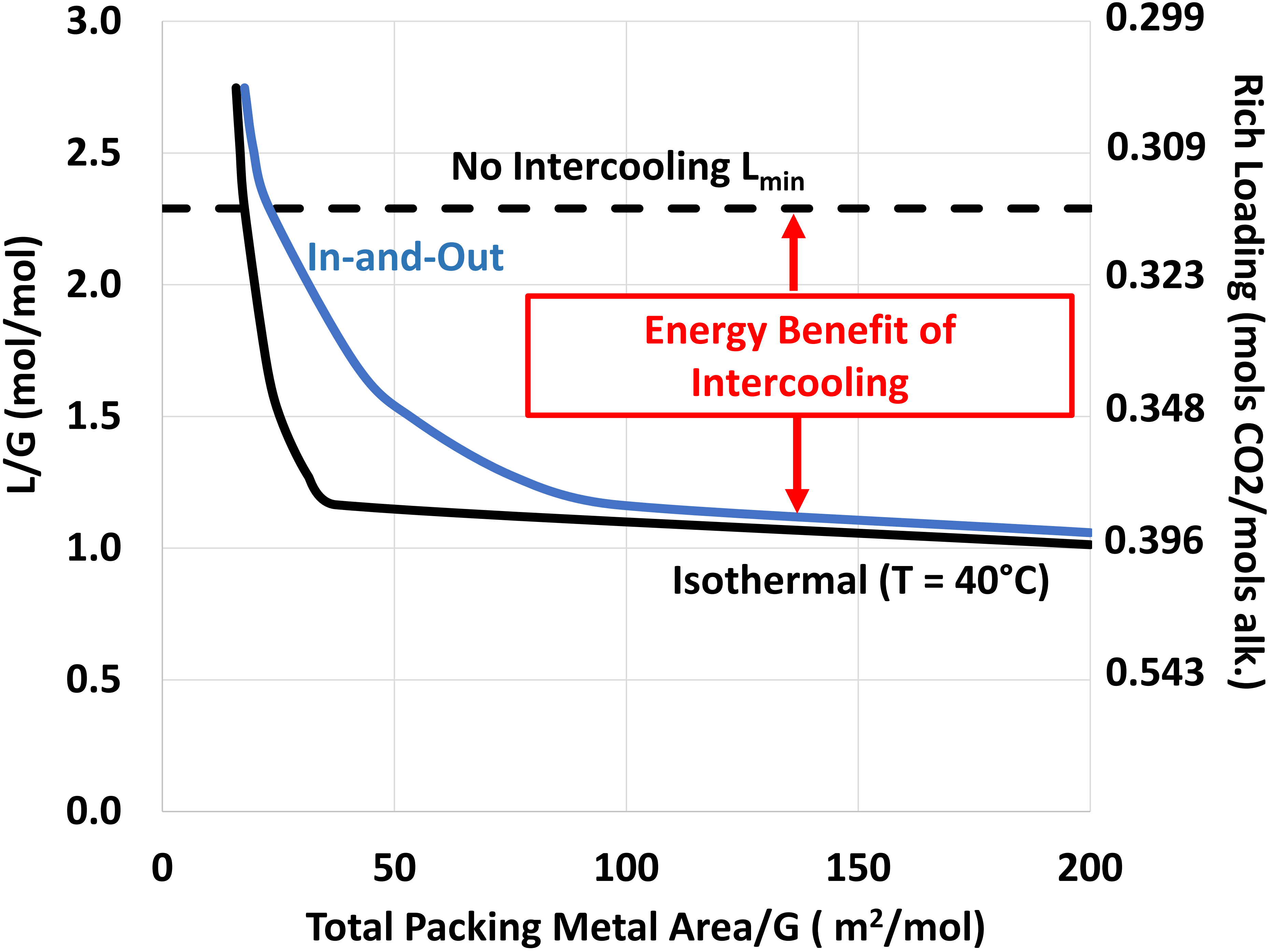


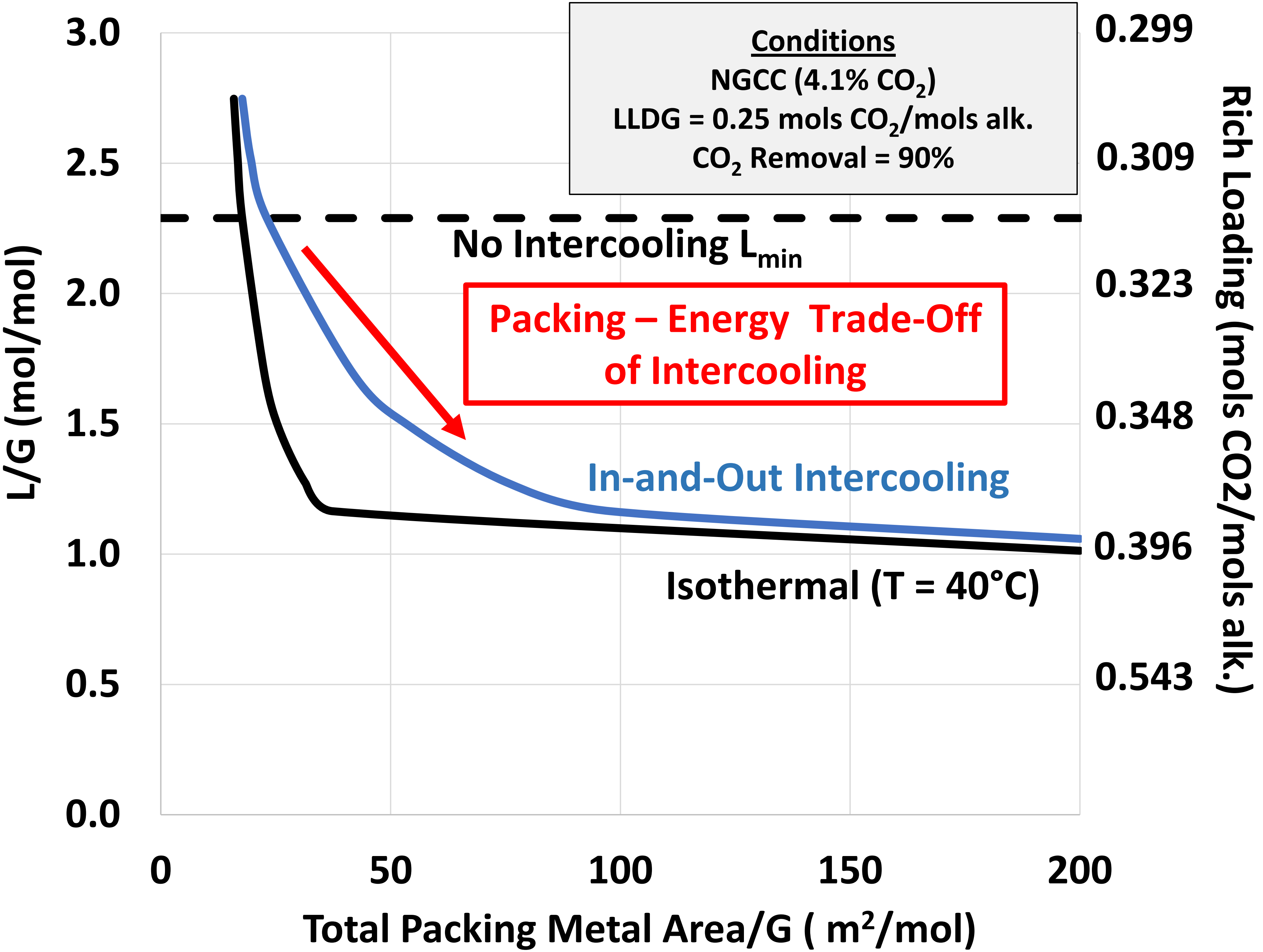
1. Recycle Rate
2. Packing Selection
3. Packing Split

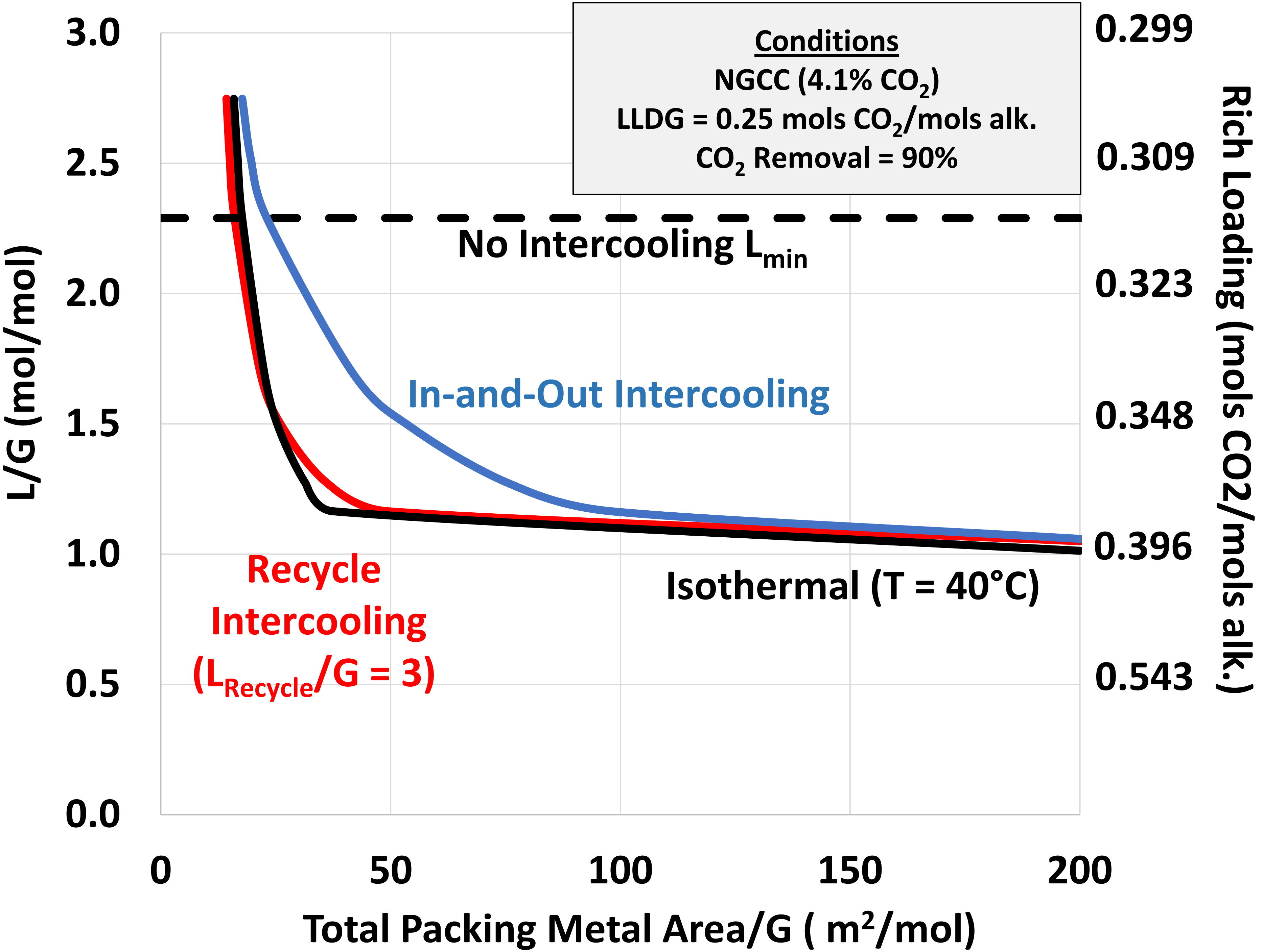
Minimize:

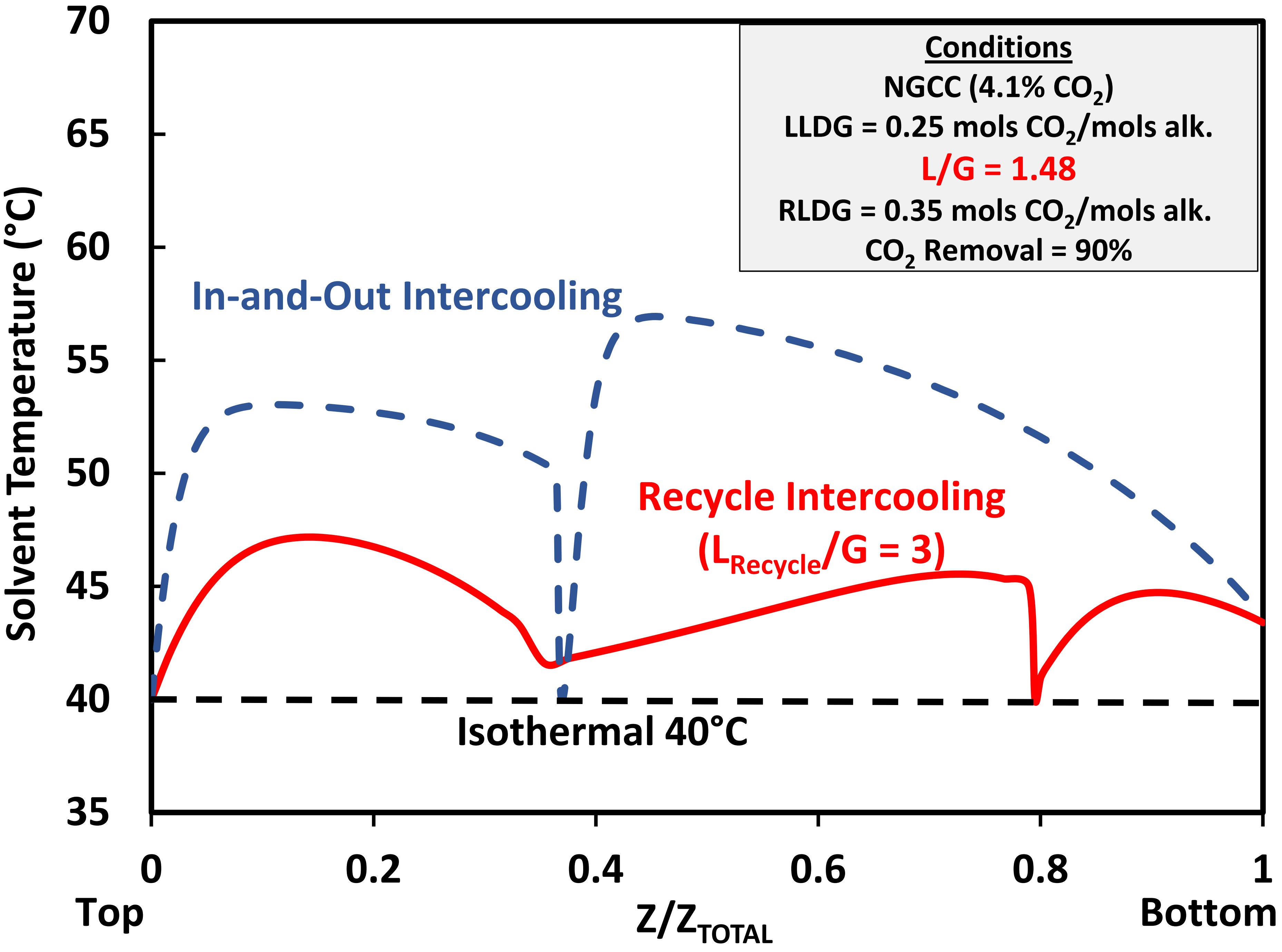
- Packing
- Pumping Costs
- Pressure Drop

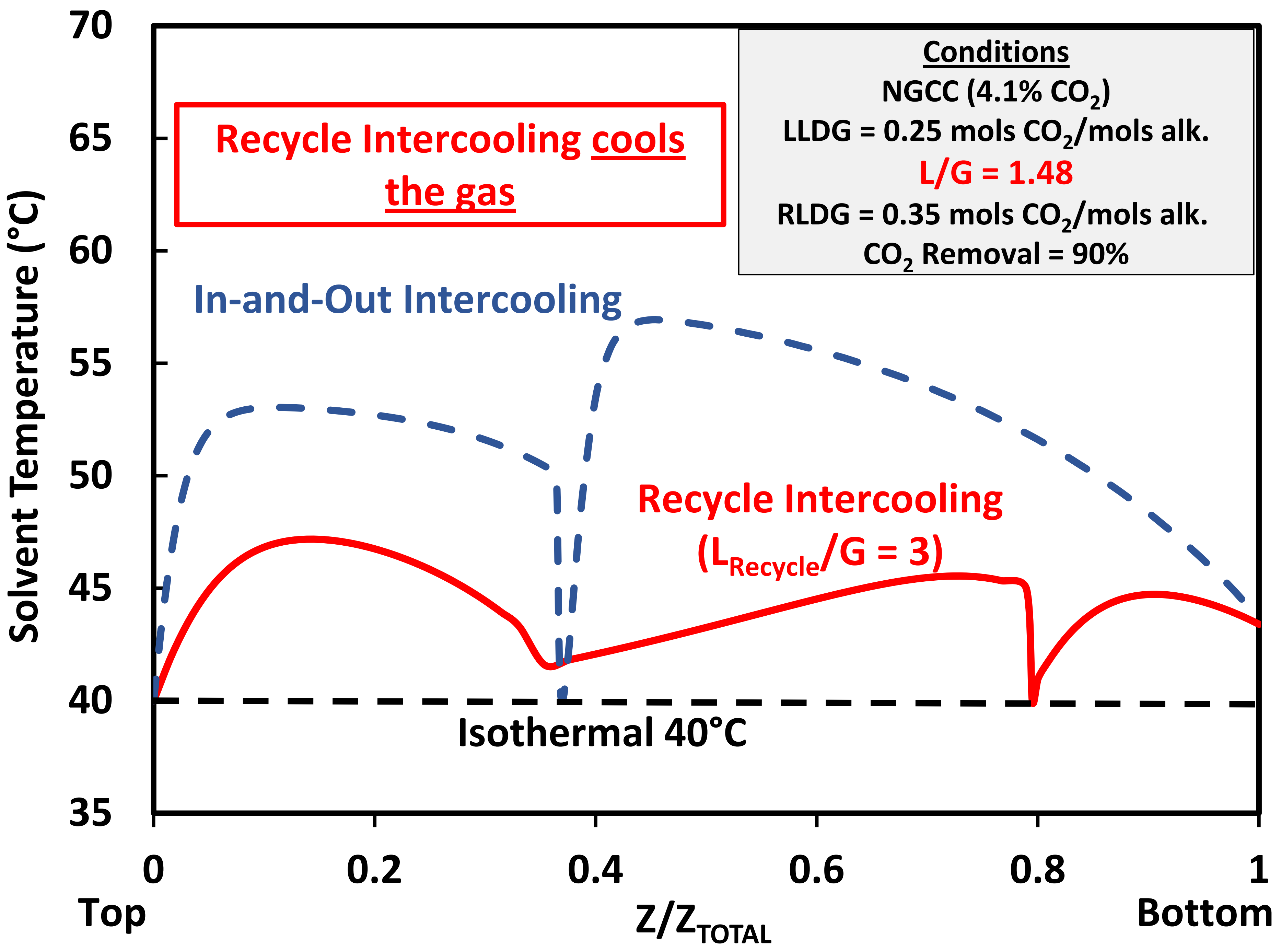

Conditions
NGCC (4.1% CO_2)
LLDG = 0.25 mols CO_2/mols alk.
CO_2 Removal = 90%
No Intercooling L_{min}
In-and-Out Intercooling
Isothermal (T = 40°C)
L/G (mol/mol)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Rich Loading (mols CO2/mols alk.)
0.299
0.309
0.323
0.348
0.396
0.543
0
50
100
150
200
Total Packing Metal Area/G (m^2/mol)


3.0
2.5
2.0
1.5
1.0
0.5
0.0
L/G (mol/mol)
0.299
0.309
0.323
0.348
0.396
0.543
Rich Loading (mols CO2/mols alk.)
0
50
100
150
200
Total Packing Metal Area/G (m²/mol)
No Intercooling Lmin
In-and-Out
Energy Benefit of Intercooling
Isothermal (T = 40°C)


3.0
2.5
2.0
1.5
1.0
0.5
0.0
L/G (mol/mol)
0
50
100
150
200
Total Packing Metal Area/G (m²/mol)
0.299
0.309
0.323
0.348
0.396
0.543
Rich Loading (mols CO2/mols alk.)
Conditions
NGCC (4.1% CO₂)
LLDG = 0.25 mols CO₂/mols alk.
CO₂ Removal = 90%
No Intercooling Lmin
Packing – Energy Trade-Off of Intercooling
In-and-Out Intercooling
Isothermal (T = 40°C)


Conditions
NGCC (4.1% CO2)
LLDG = 0.25 mols CO2/mols alk.
CO2 Removal = 90%
No Intercooling Lmin
In-and-Out Intercooling
Recycle Intercooling (LRecycle/G = 3)
Isothermal (T = 40°C)
L/G (mol/mol)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
Total Packing Metal Area/G (m2/mol)
0.299
0.309
0.323
0.348
0.396
0.543
Rich Loading (mols CO2/mols alk.)


Conditions
NGCC (4.1% CO_2)
LLDG = 0.25 mols CO_2/mols alk.
L/G = 1.48
RLDG = 0.35 mols CO_2/mols alk.
CO_2 Removal = 90%
In-and-Out Intercooling
Recycle Intercooling
($L_{Recycle}$/G = 3)
Isothermal 40°C
Solvent Temperature (°C)
70
65
60
55
50
45
40
35
0
0.2
0.4
0.6
0.8
1
Top
Z/Z_{TOTAL}
Bottom



Recycle Intercooling cools the gas

Conditions

NGCC (4.1% CO_2)

LLDG = 0.25 mols CO_2/mols alk.

L/G = 1.48

RLDG = 0.35 mols CO_2/mols alk.

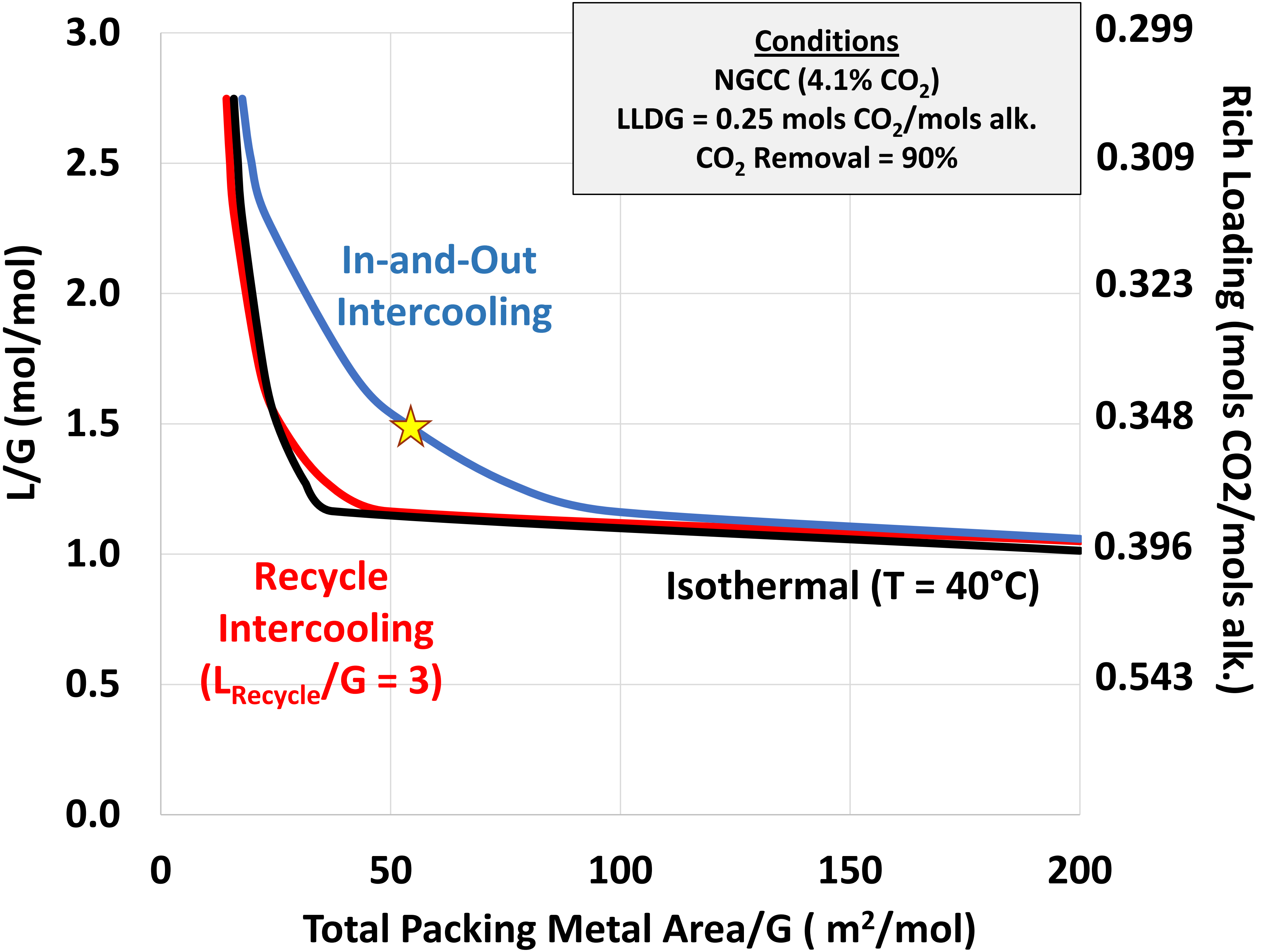
CO_2 Removal = 90%

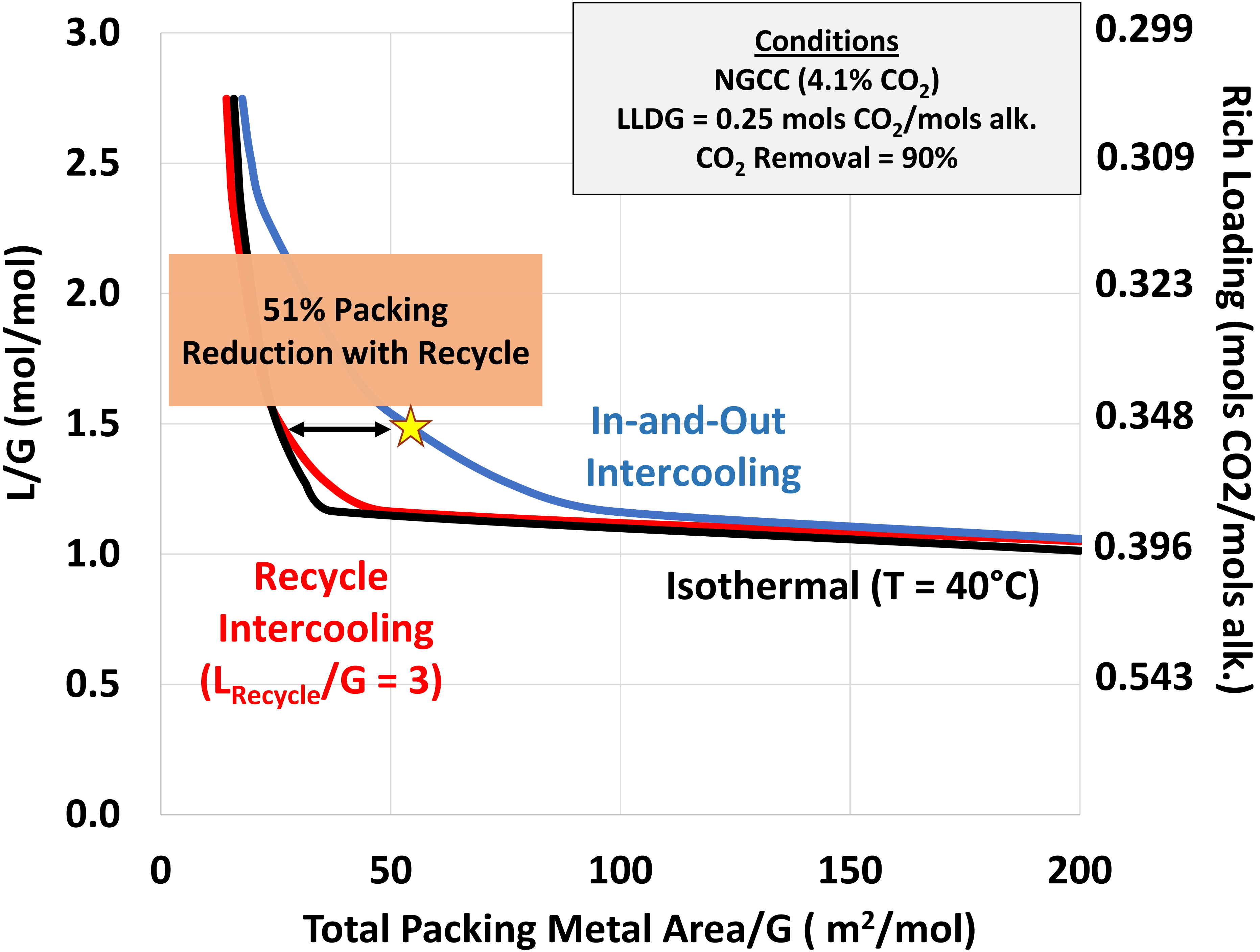
Mass Transfer Effects

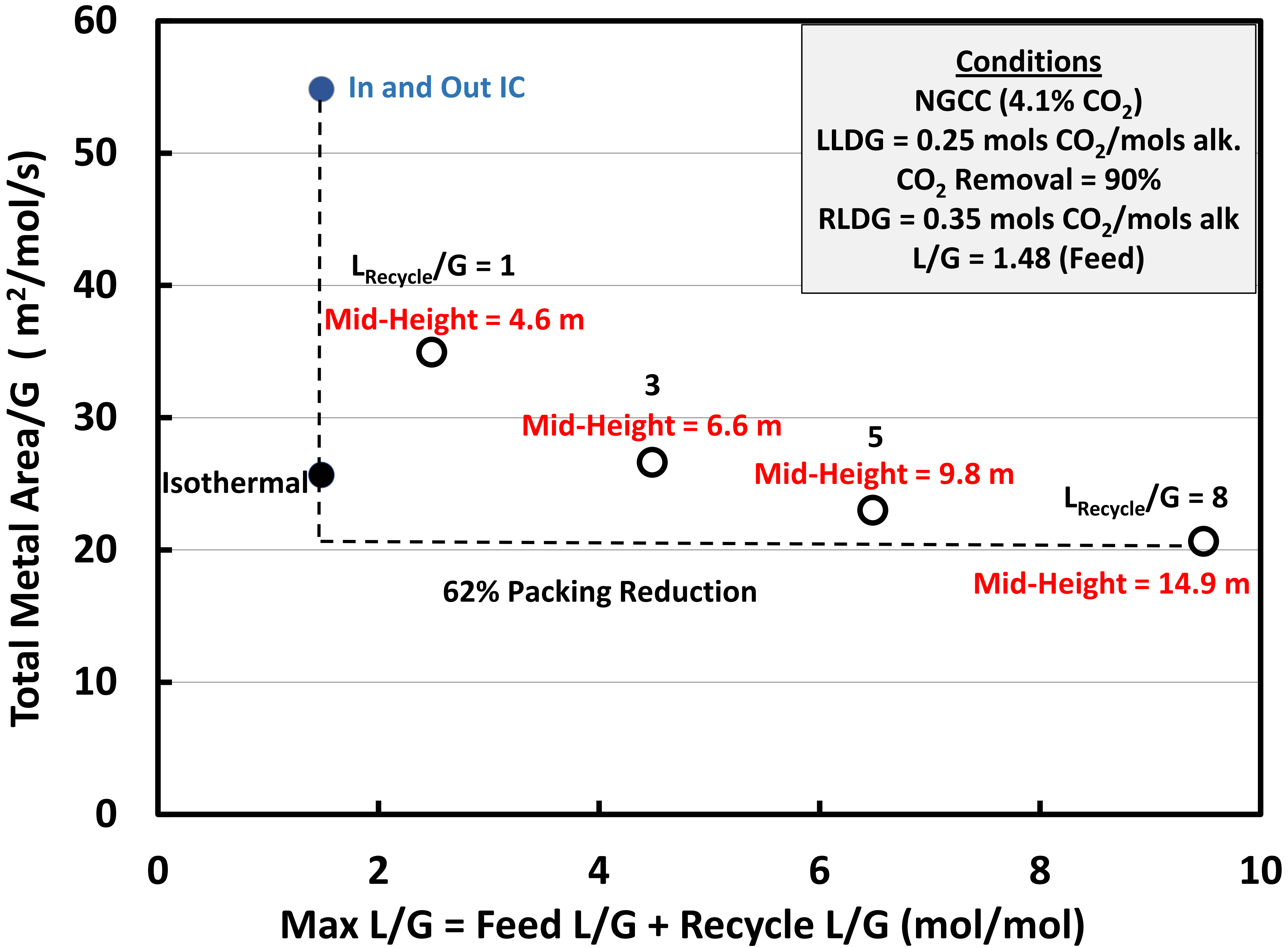
$$\frac{k_L}{D_{AB}^{0.5}} \sim \left(\frac{u_L}{a_P}\right)^{\mathbf{0.63}}$$

$$\frac{a_e}{a_p} \sim \left(\frac{u_L}{a_P}\right)^{\mathbf{0.16}}$$

- u_L/a_p = Liquid rate per perimeter (high recycle rate/coarse packing)
  - Increased surface to bulk mixing (surface renewal)
  - Enhanced wetted area from droplets, rippling of solvent


Conditions
NGCC (4.1% CO2)
LLDG = 0.25 mols CO2/mols alk.
CO2 Removal = 90%
In-and-Out Intercooling
Recycle Intercooling (LRecycle/G = 3)
Isothermal (T = 40°C)
L/G (mol/mol)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Rich Loading (mols CO2/mols alk.)
0.299
0.309
0.323
0.348
0.396
0.543
0
50
100
150
200
Total Packing Metal Area/G (m²/mol)


Conditions
NGCC (4.1% CO_2)
LLDG = 0.25 mols CO_2/mols alk.
CO_2 Removal = 90%
51% Packing Reduction with Recycle
In-and-Out Intercooling
Recycle Intercooling ($L_{Recycle}$/G = 3)
Isothermal (T = 40°C)
L/G (mol/mol)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Rich Loading (mols CO2/mols alk.)
0.299
0.309
0.323
0.348
0.396
0.543
0
50
100
150
200
Total Packing Metal Area/G (m^2/mol)



Conditions
NGCC (4.1% CO2)
LLDG = 0.25 mols CO2/mols alk.
CO2 Removal = 90%
RLDG = 0.35 mols CO2/mols alk
L/G = 1.48 (Feed)
In and Out IC
LRecycle/G = 1
Mid-Height = 4.6 m
3
Mid-Height = 6.6 m
5
Mid-Height = 9.8 m
LRecycle/G = 8
Mid-Height = 14.9 m
Isothermal
62% Packing Reduction
Total Metal Area/G (m2/mol/s)
Max L/G = Feed L/G + Recycle L/G (mol/mol)
0
10
20
30
40
50
60
0
2
4
6
8
10

Conclusions

- Intercooling can provide significant energy benefits
  - Addresses temperature related mass transfer pinch
  - All intercooling designs approach similar minimum solvent rate (max RLDG) in the limit of infinite packing
  - **In-and-Out Intercooling requires additional packing** to realize energy benefits
- Recycle intercooling achieves energy benefits while minimizing additional packing requirement
  - Lower average column temperature = Larger driving forces
  - Enhanced mass transfer via turbulence in recycle section
- Economic optimization required to identify operating conditions for recycle intercooling

Acknowledgements

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- Rochelle Research Group Members
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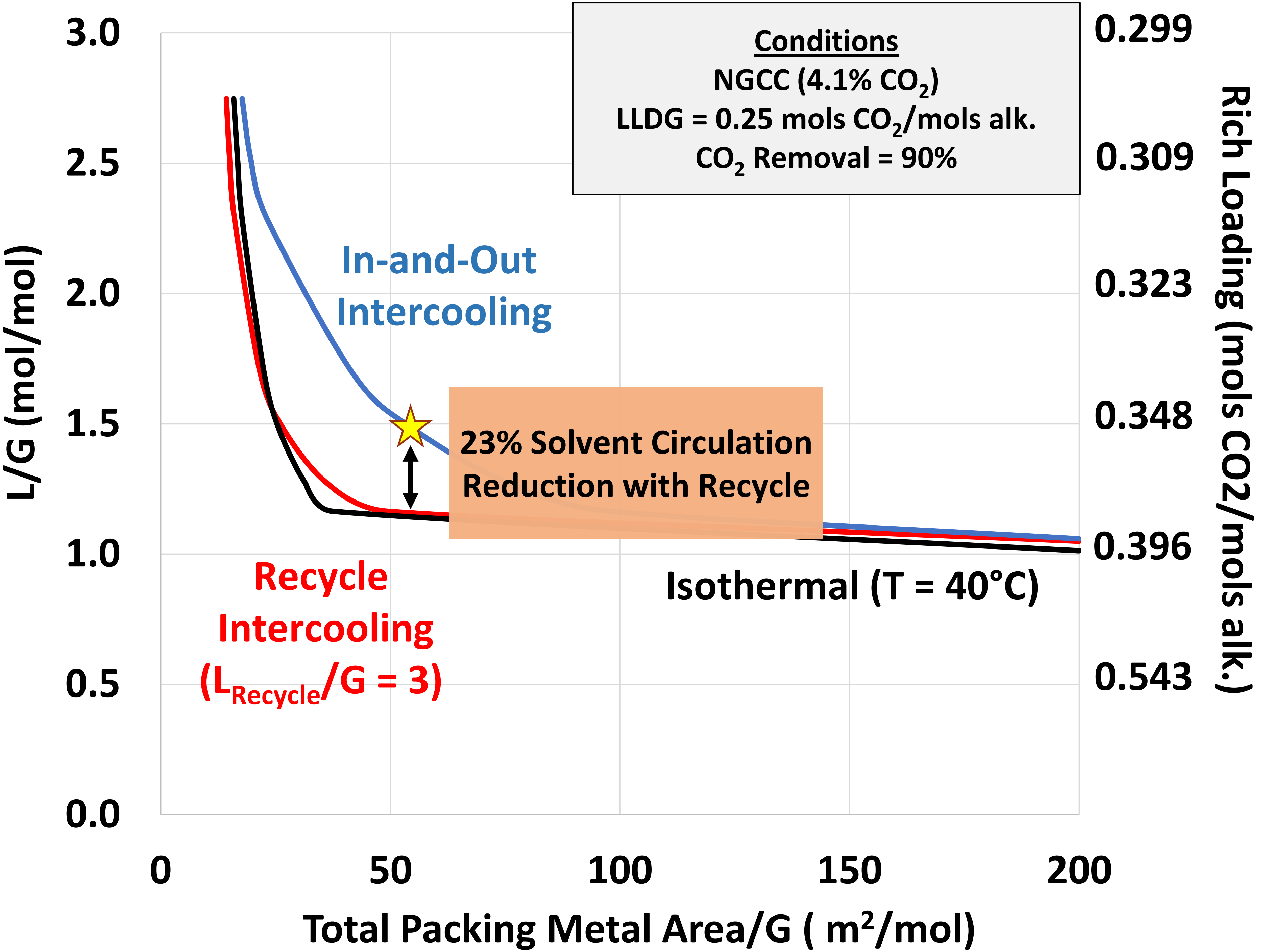


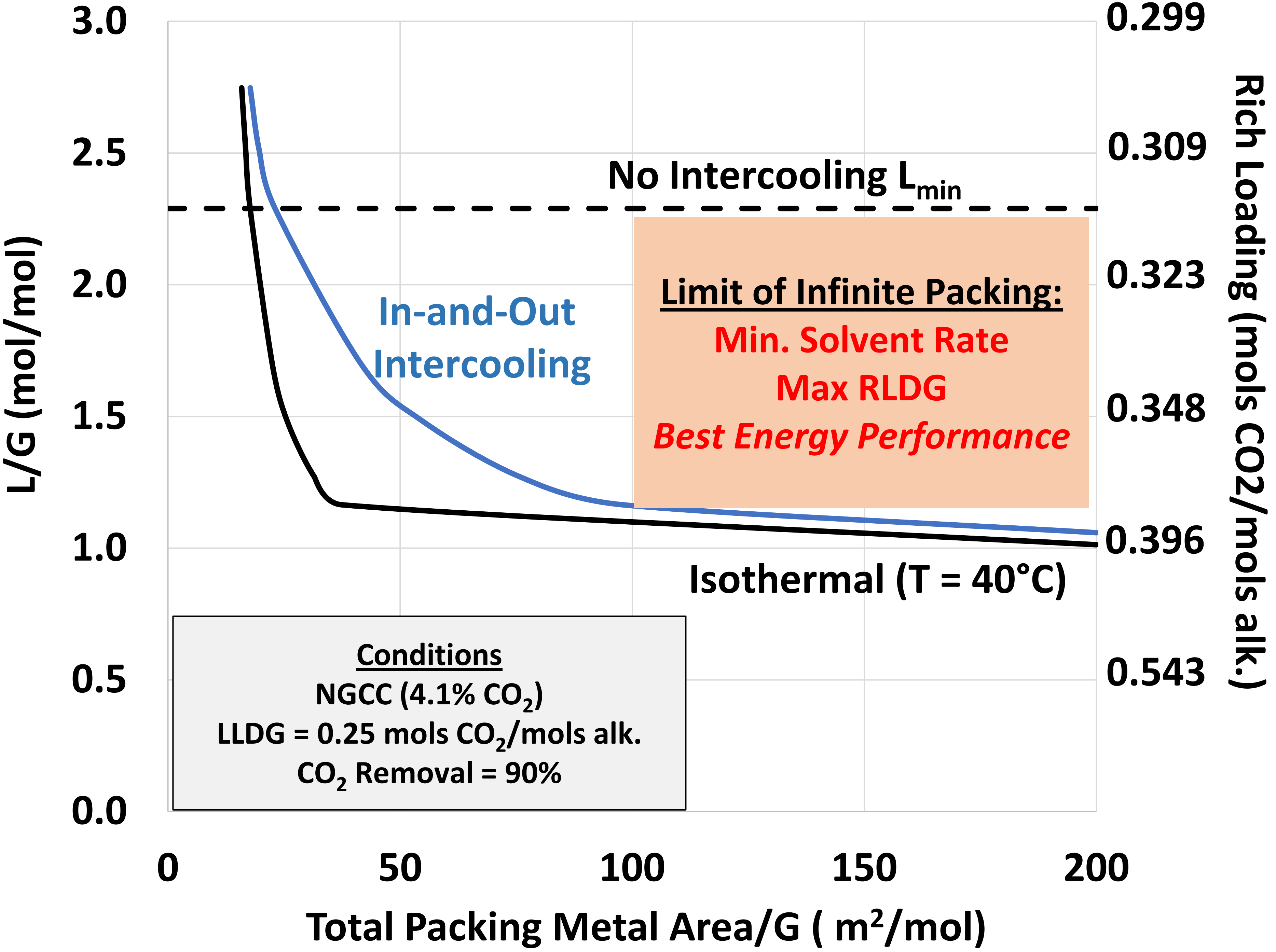
Conditions

NGCC (4.1% CO_2)

LLDG = 0.25 mols CO_2/mols alk.

CO_2 Removal = 90%

23% Solvent Circulation Reduction with Recycle



Limit of Infinite Packing:

Min. Solvent Rate

Max RLDG

Best Energy Performance

Conditions

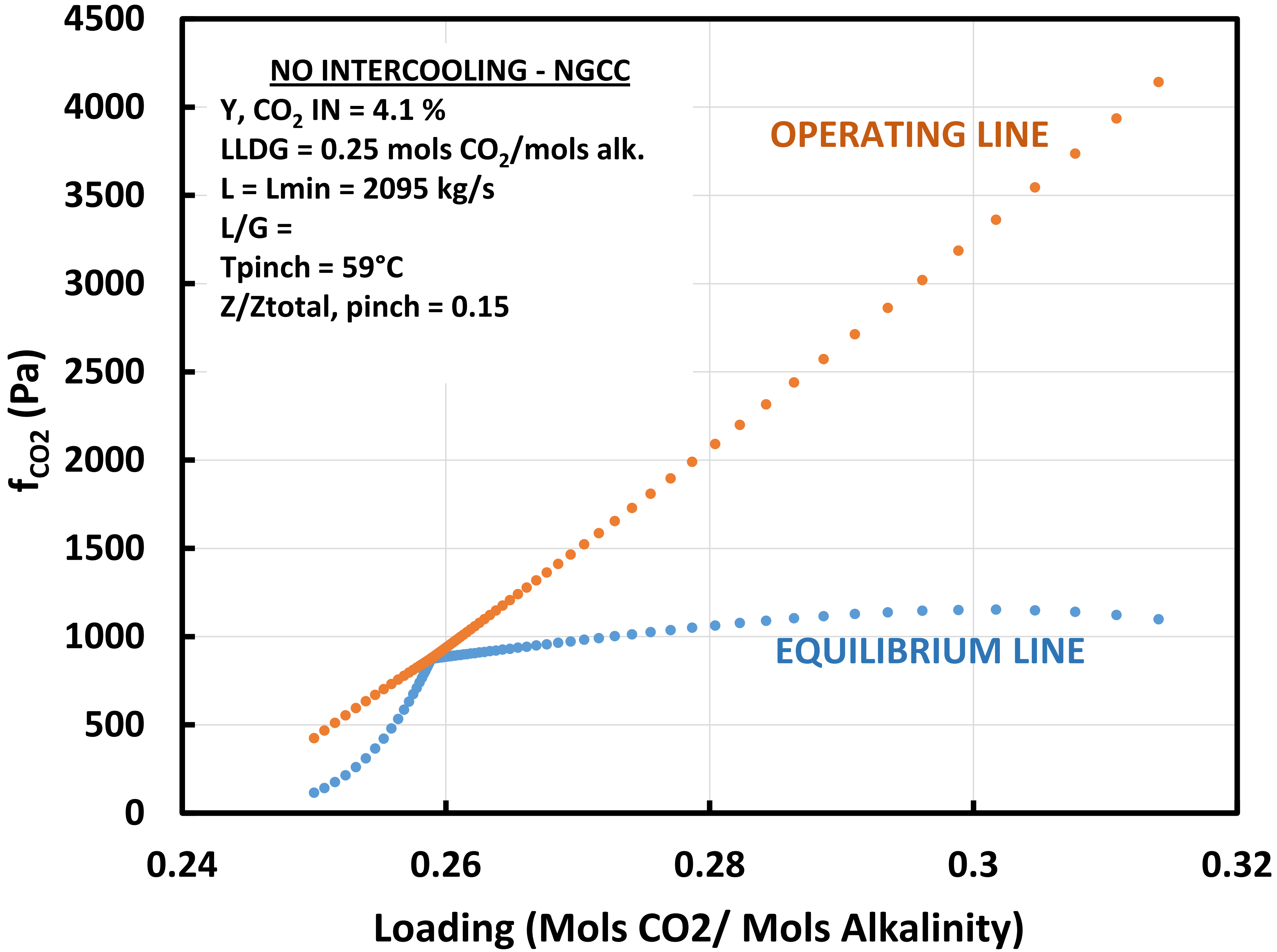
NGCC (4.1% CO_2)

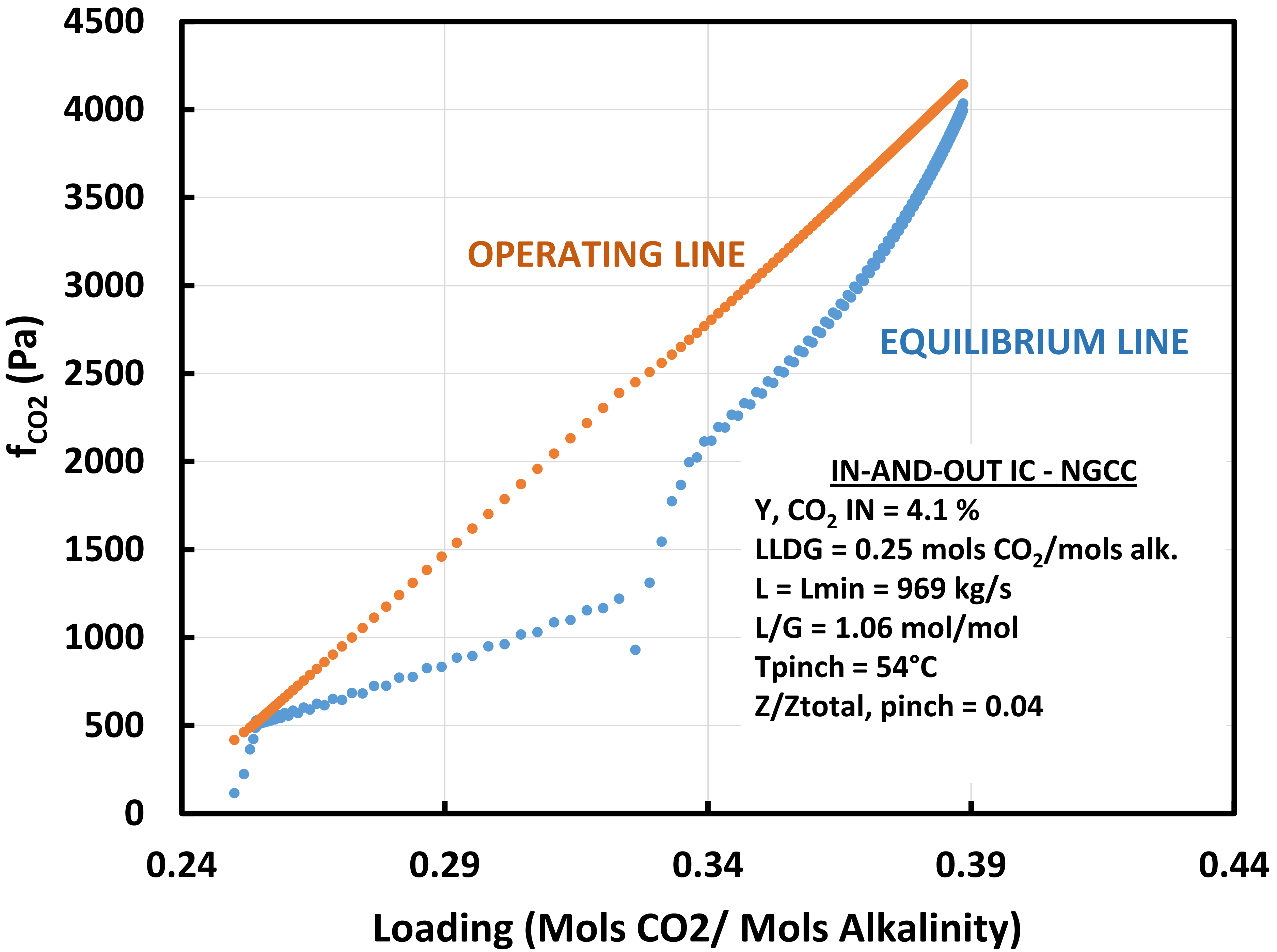
LLDG = 0.25 mols CO_2/mols alk.

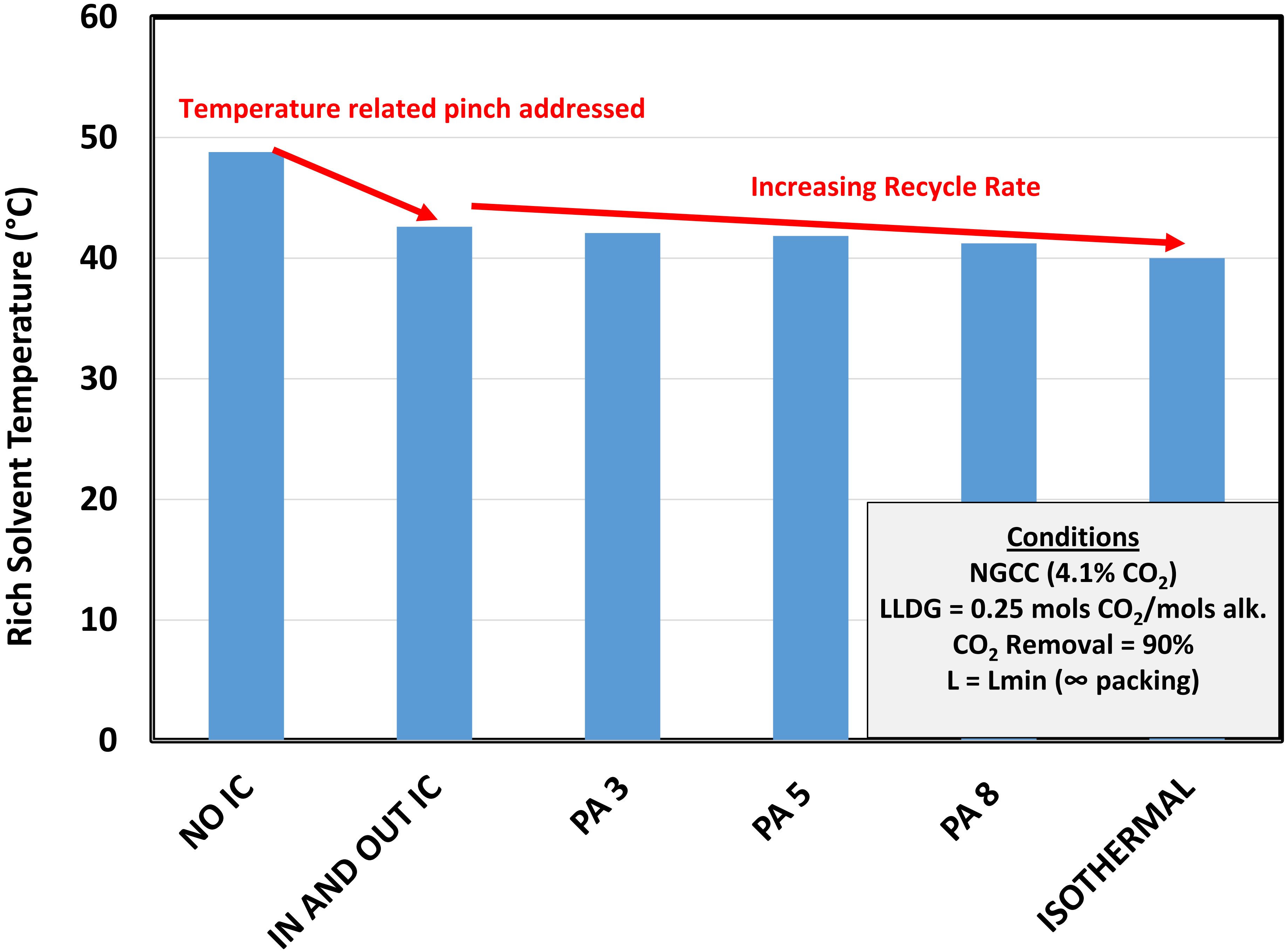
CO_2 Removal = 90%

Why Recycle Intercooling?

- Developed originally for NGCC application
  - Low L/G – heat carried in ***gas*** (T bulge at top of column)
  - Recycle: High L/G in well-mixed section of packing – ***COOL GAS***
- Additional Benefit: High Liquid Rate (recycle) per wetted perimeter (coarse packing)
  - Turbulence on liquid side in recycle section:
    1. Additional gas-liquid contact area
    2. Enhanced surface renewal of liquid due to turbulence


NO INTERCOOLING - NGCC
Y, CO2 IN = 4.1 %
LLDG = 0.25 mols CO2/mols alk.
L = Lmin = 2095 kg/s
L/G =
Tpinch = 59°C
Z/Ztotal, pinch = 0.15
OPERATING LINE
EQUILIBRIUM LINE
fCO2 (Pa)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0.24
0.26
0.28
0.3
0.32
Loading (Mols CO2/ Mols Alkalinity)


4500
4000
3500
3000
2500
2000
1500
1000
500
0
f_{CO2} (Pa)
0.24
0.29
0.34
0.39
0.44
Loading (Mols CO2/ Mols Alkalinity)
OPERATING LINE
EQUILIBRIUM LINE
IN-AND-OUT IC - NGCC
Y, CO_2 IN = 4.1 %
LLDG = 0.25 mols CO_2/mols alk.
L = Lmin = 969 kg/s
L/G = 1.06 mol/mol
Tpinch = 54°C
Z/Ztotal, pinch = 0.04



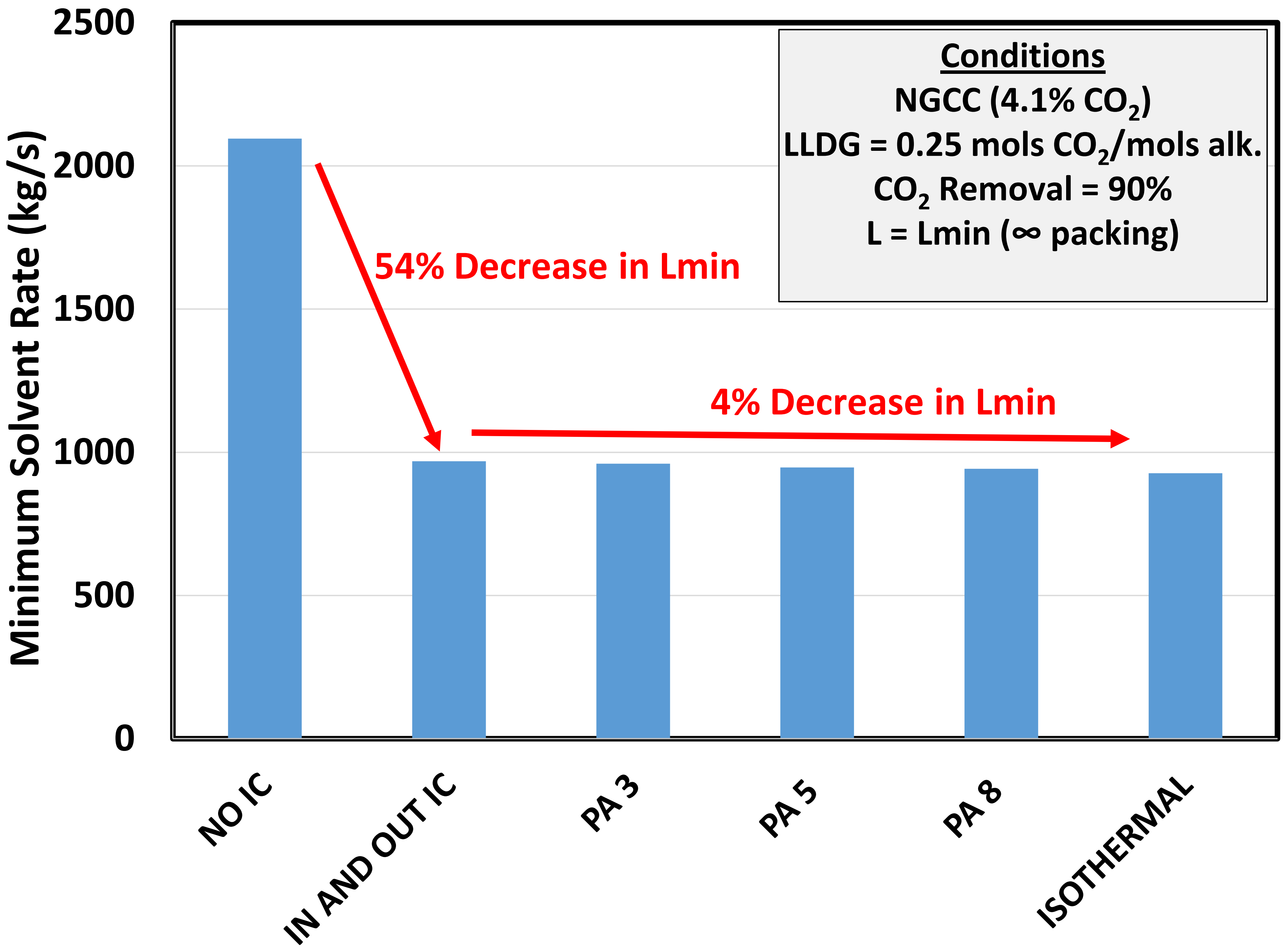
Conditions

NGCC (4.1% CO_2)

LLDG = 0.25 mols CO_2/mols alk.

CO_2 Removal = 90%

L = Lmin (∞ packing)


Minimum Solvent Rate (kg/s)
2500
2000
1500
1000
500
0
Conditions
NGCC (4.1% CO$_2$)
LLDG = 0.25 mols CO$_2$/mols alk.
CO$_2$ Removal = 90%
L = Lmin (∞ packing)
54% Decrease in Lmin
4% Decrease in Lmin
NO IC
IN AND OUT IC
PA 3
PA 5
PA 8
ISOTHERMAL

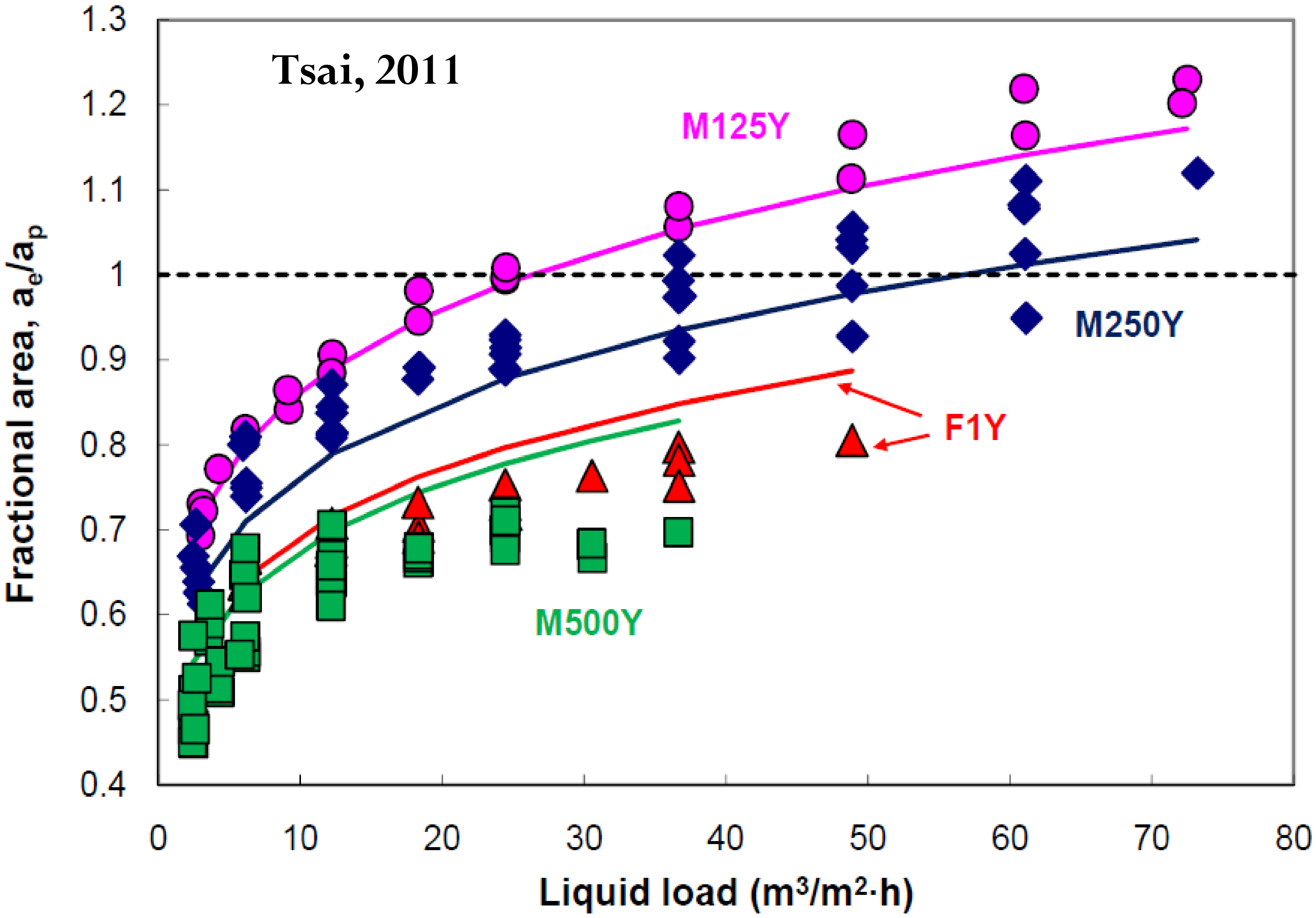
Mass Transfer Effects

$$\frac{k_L}{D_{AB}^{0.5}} = A * \left(\frac{u_L}{a_P}\right)^{\mathbf{0.63}} \left(M_p\right)^{0.54} \left(\mu_L\right)^{-0.5}$$

$$\frac{a_e}{a_p} = A * \left(\frac{u_L}{a_P}\right)^{\mathbf{0.16}} (g)^{0.04} \left(\frac{\rho_L}{\sigma}\right)^{0.12}$$

- u_L/a_p = Liquid rate per perimeter (RECYCLE BENEFITS)
- M_p = Mixing point density (function of packing geometry)

Additional Mass transfer area ~f(Liquid load/perimeter)



Hanley and Chen Mass Transfer Model

- $$k_L = 0.33 * Re_L * Sc_L^{\frac{1}{3}} * \left(\frac{\mathrm{c_L} * D}{\mathrm{d_h}}\right), \mathrm{d_h} = \frac{4 * \varepsilon}{\mathrm{a_p}}$$

$$\mathbf{k_L \sim u_L^1 \ , \ k_L \sim a_p^0}$$

  - k_L effects **not** easily isolated

$$\frac{1}{K_G} = \frac{1}{k_G} + \frac{1}{k_G''} + \frac{m}{k_L}, \qquad m = \frac{\Delta P_{CO_2}}{\Delta[CO_2]_T}$$

- **Absolute value of k_L** relative to reaction rates, equilibrium predictions, and gas-side resistance determine impact of k_L on mass transfer efficiency