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Process and Material Design for Micro-Encapsulated Ionic Liquids in Post-Combustion CO_2 Capture

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Outline

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  - Microencapsulation technology
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  - Sensitivity of Microcapsule diameter
- Concluding remarks

Background

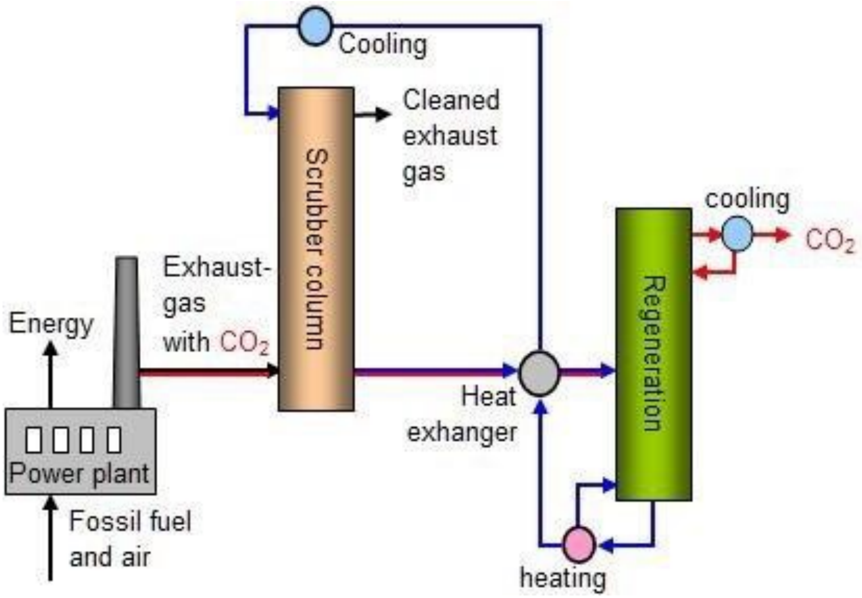
Ionic Liquids for CO_2 capture (post-combustion)

ILs are nonvolatile salts with low melting points, wide liquid phase operating ranges, and endless tunability.

- Potential advantages
  - Require no added water to serve as a diluent
  - Good thermal and oxidative stability
  - No evaporation into cleaned gas stream

- Potential disadvantages (early-generation ILs)
  - Viscosity increase after absorbing CO_2
  - Low CO_2 capacity (physical)

- Aprotic Heterocyclic Anion (AHA) ILs offer solutions to these issues (Gurkan *et al*. 2010)

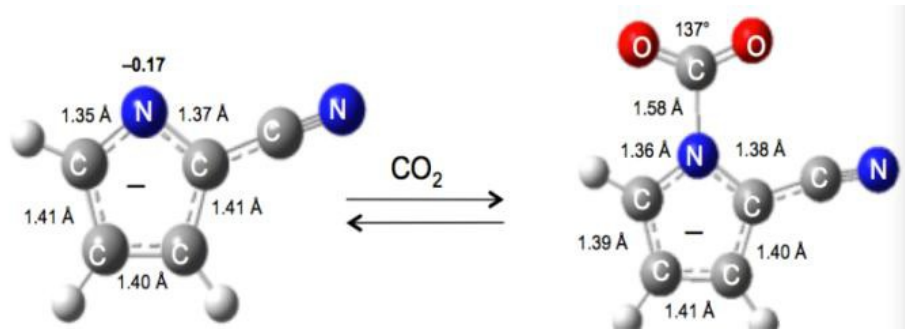


http://www.bellona.org/factsheets/1191913555.13

AHA ILs -- Chemically complexing IL design for post-combustion carbon capture

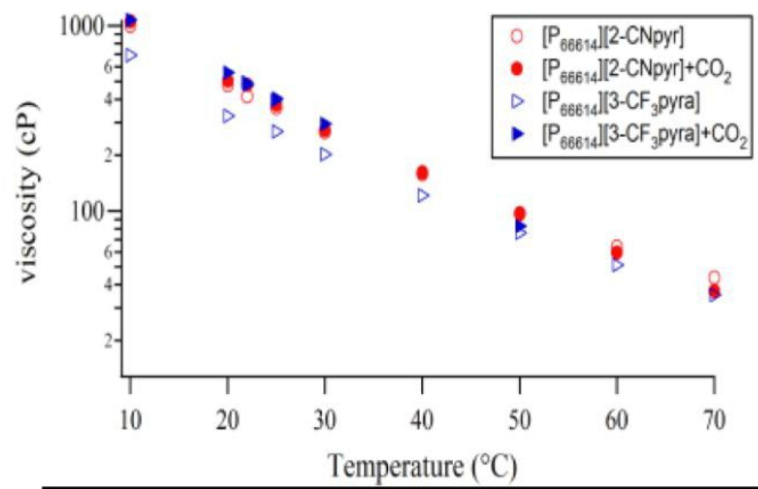
1. Double the capacity compared to MEA

Demonstrated experimentally that a 1:1 reaction stoichiometry is achieved[1]



2. Eliminate viscosity increases

Aprotic heterocyclic anion (AHA) can hinder the formation of the hydrogen bonding which is the main cause of IL's viscosity increases[1]



3. Optimize reaction enthalpy

Using equilibrium-based process optimization, we identified the optimal reaction enthalpy of CO_2 absorption is around **– 50 KJ/mol**[2]

1. Gurkan, B., et al. *The Journal of Physical Chemistry Letters* 1 (2010): 3494-3499.
2. Hong, B., et al., *Industrial & Engineering Chemistry Research* 55 (2016): 8432-8449.

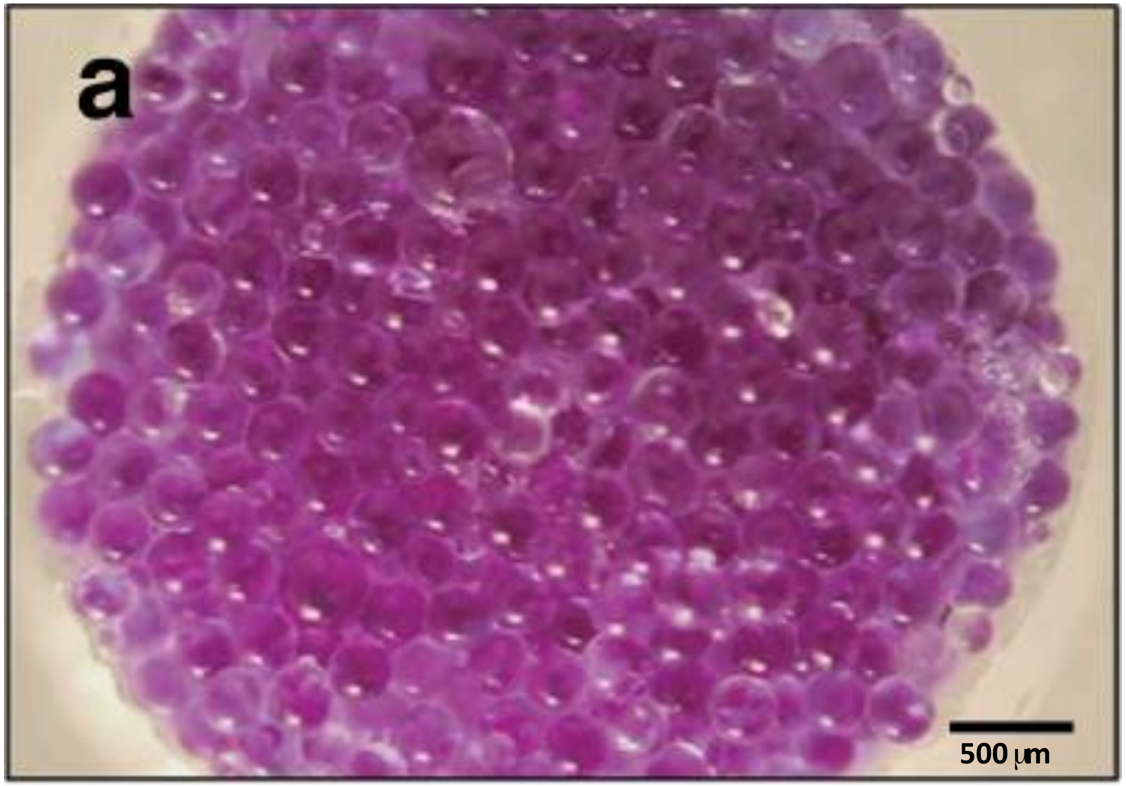
AHAs in a packed column absorber

The typical viscosity of AHAs at 40 ^{o}C is 100 cP.
This results in relatively:

- Low CO_2 diffusion coefficient
- Low wetted surface area
- High pressure drop

Microencapsulation technology

- Improve reactor productivity by increasing mass transfer area.
- Improve the reactor temperature control by fluidization.



Vericella J J, Baker S E, Stolaroff J K, et al. Nature Communications, 2015, 6:6124.

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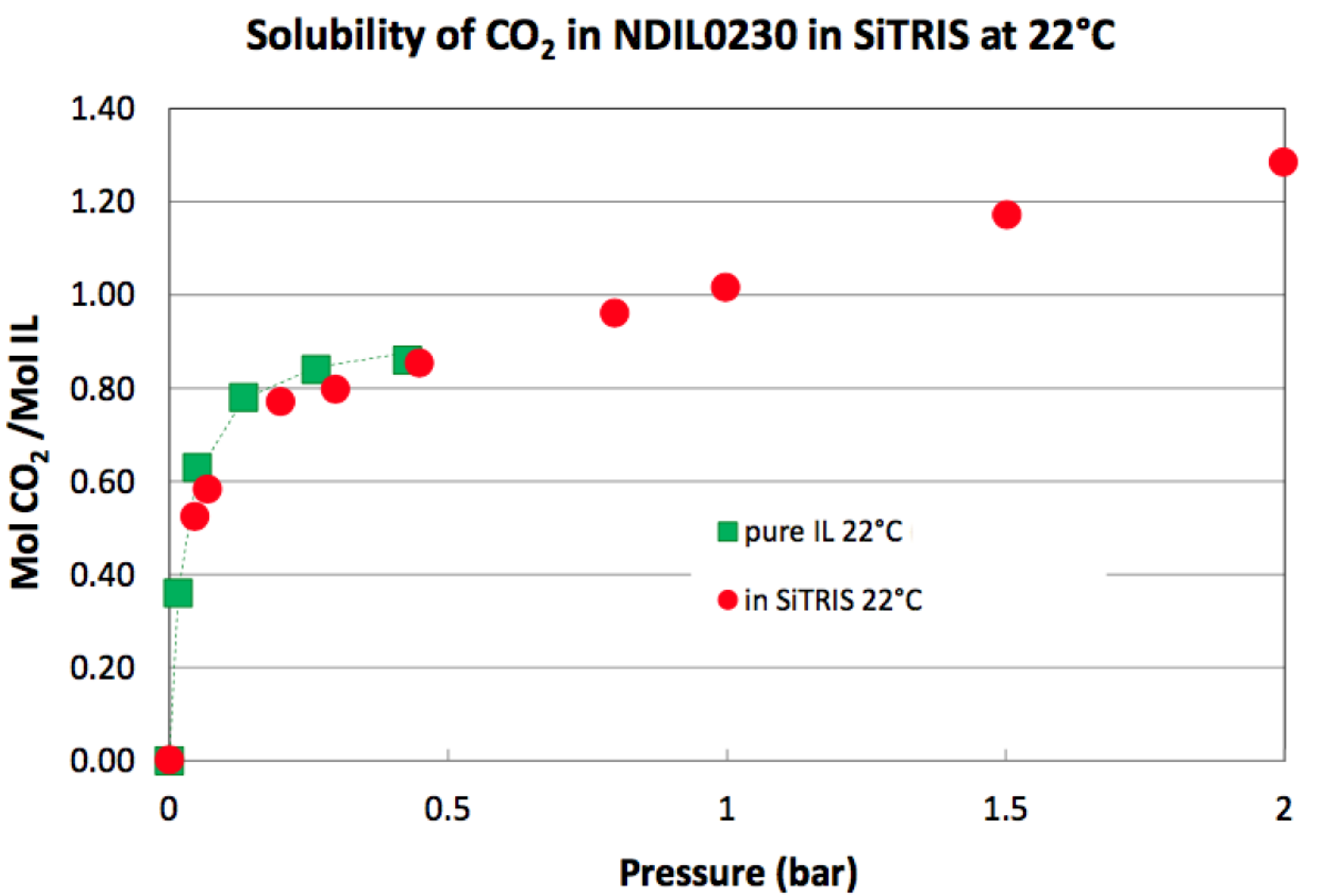
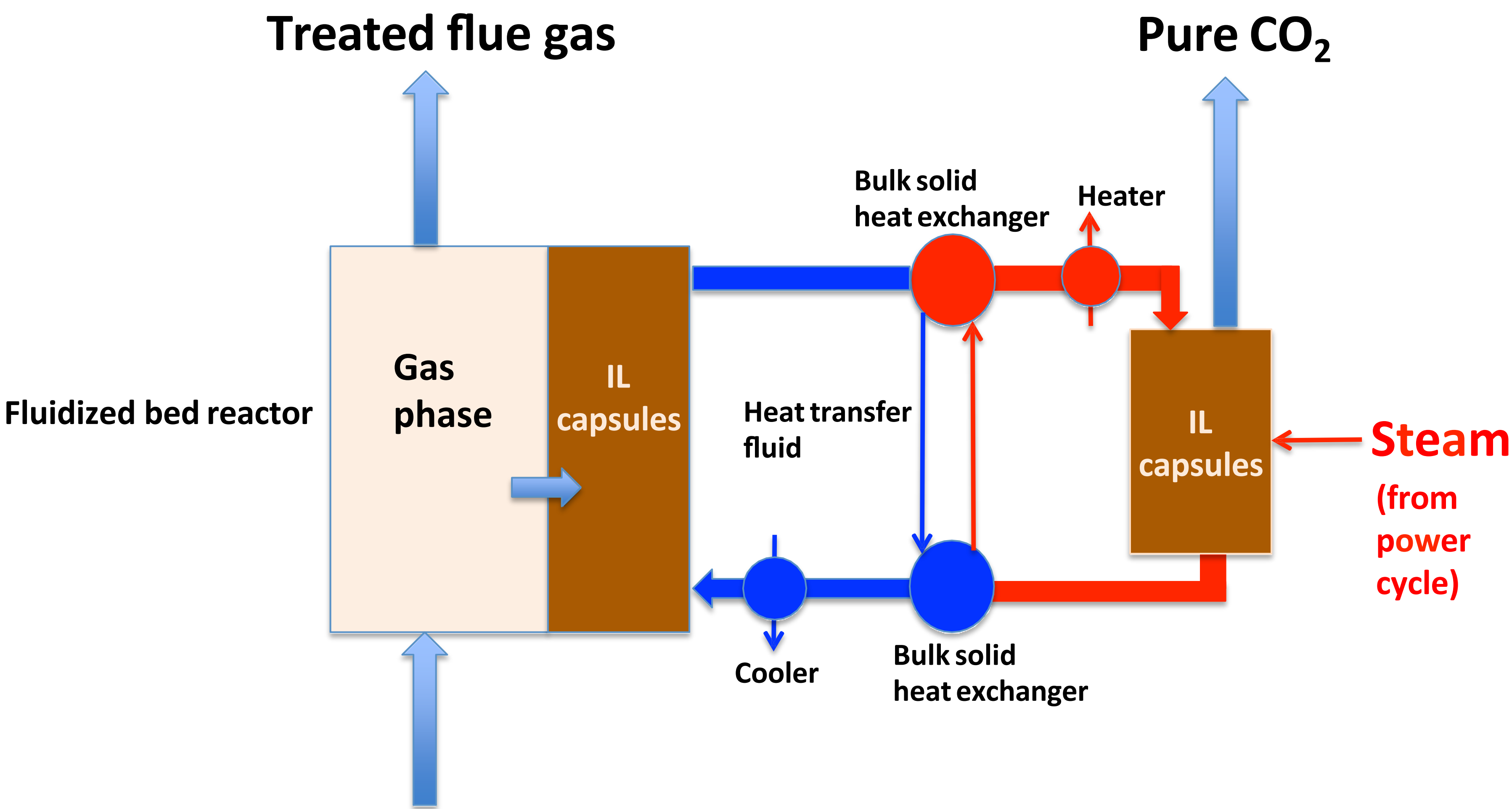
Encapsulated IL maintains capacity



(Measured by Tangqiumei Song)

Process design

Process schematics



Flue gas (760 m^3/s, containing 15% of CO_2)
From Pulverized Coal power plant with 550
MWe net output

Process conditions (not optimized) used in analysis

Process operating conditions:

- T_a = 308.15 K
- P_a = 1 bar
- T_s = 473.15 K
- P_s = 1 bar

Fluidization conditions (riser type):

- Average solid fraction = 0.1
- Exit solid fraction = 0.01
- Solid circulation rate = 7.5 m^3/s

Flue gas conditions: (Case 10 in NETL report 2010)[1]

- Flue gas flow rate = 99950 kmol/hr (after water knockout)
- CO_2 mole fraction : 0.15 (after water knockout)

1.Black, James. "Cost and performance baseline for fossil energy plants, Volume 1: Bituminous coal and natural gas to electricity." *National Energy Technology Laboratory: Washington, DC, USA* (2010).

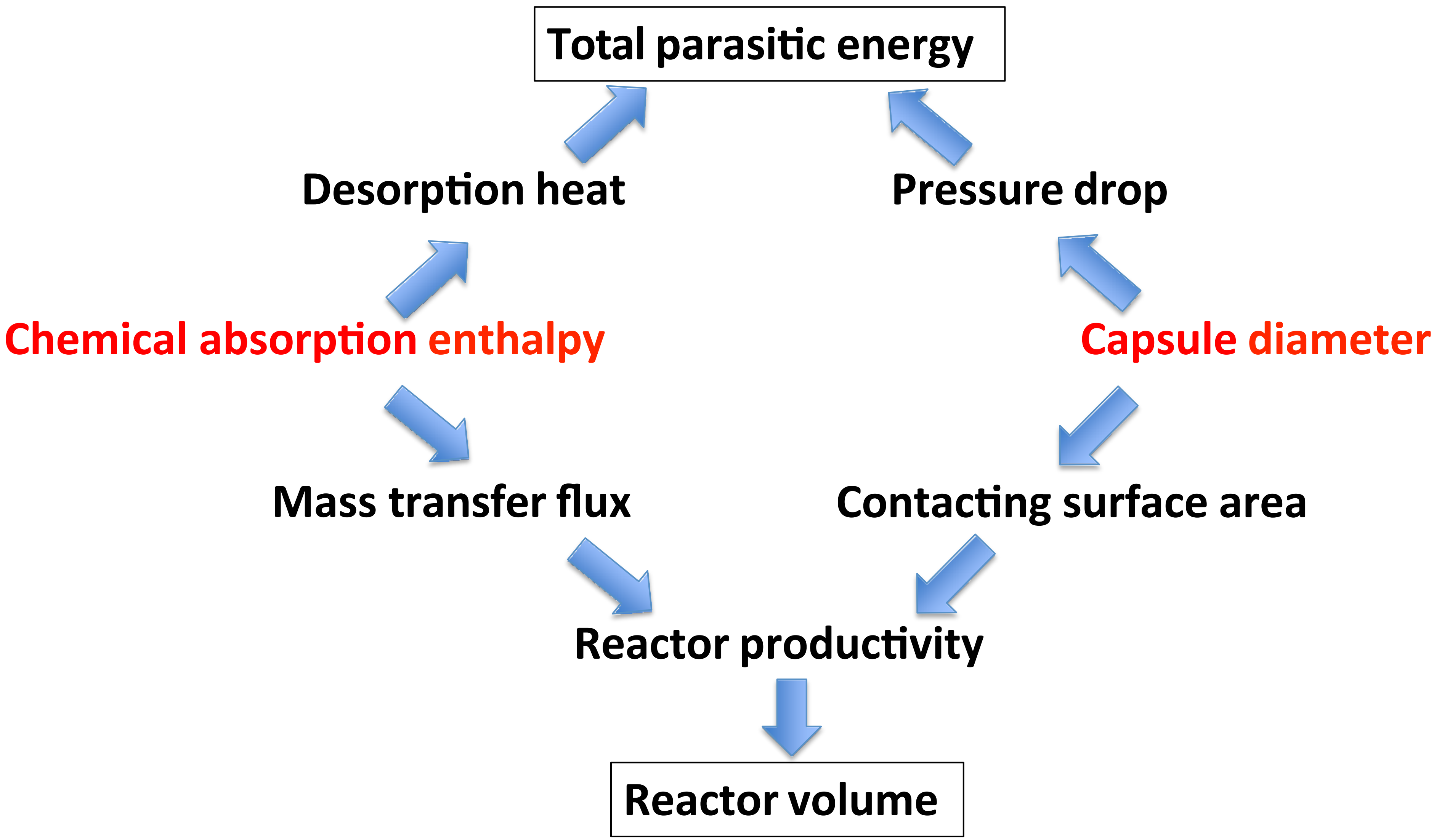
IL properties used in analysis

$[P_{66614}][2\text{-}CNpyr]$:

- Chemical absorption entropy[1] = −130 J/(mol K)
- IL viscosity = 100 cP
- Second order reaction rate[2] = 10 m^3/(mol s)
- IL density[1] = 0.892 (g/cm^3)
- IL molecular weight[1] = 575 (g/mol)

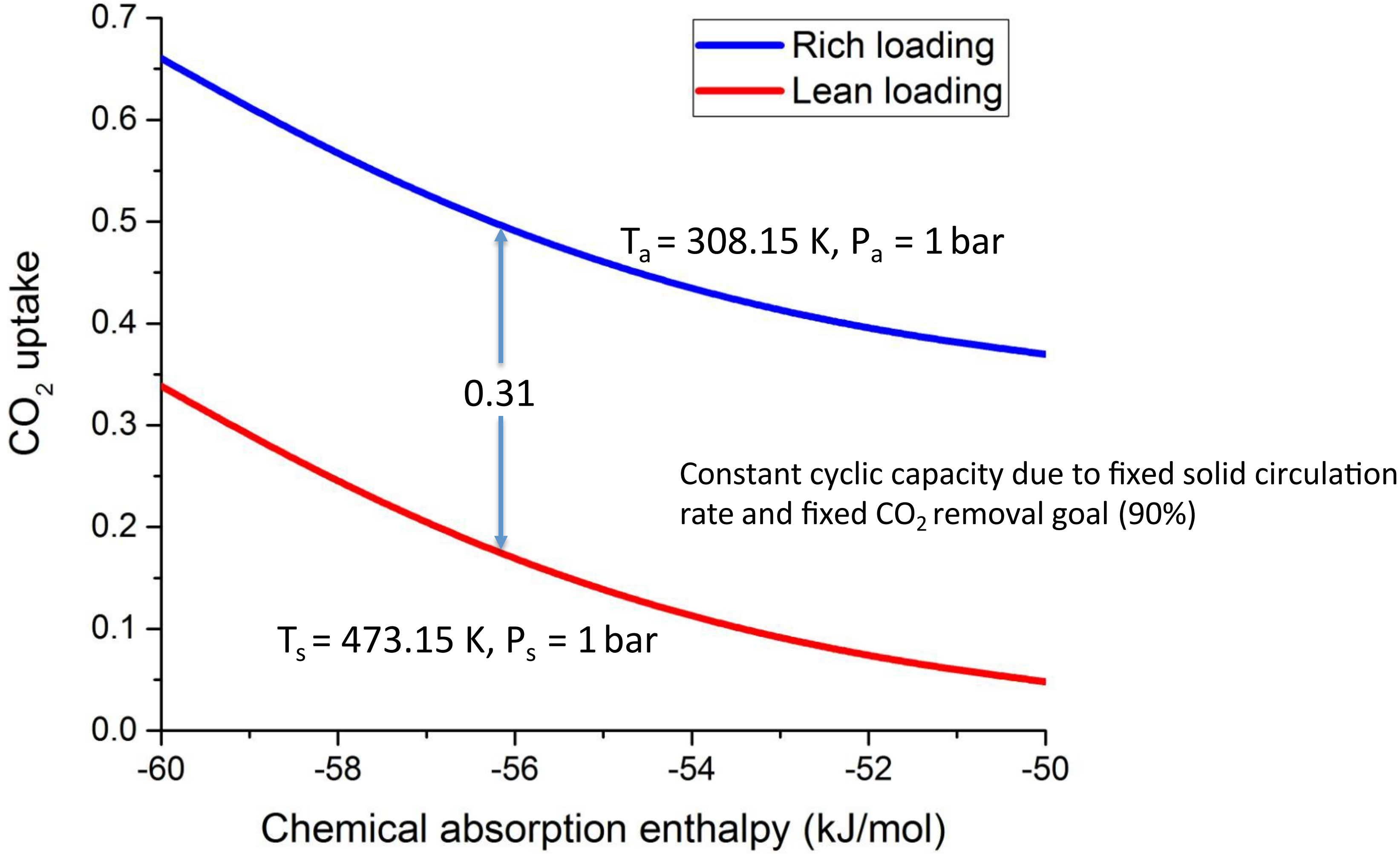
1. Seo S. et al. The Journal of Physical Chemistry B, 2014, 118: 5740-5751.
2. Gurkan B. et al. Physical Chemistry Chemical Physics, 2013, 15: 7796-7811.

Process performance improvement with better engineered properties

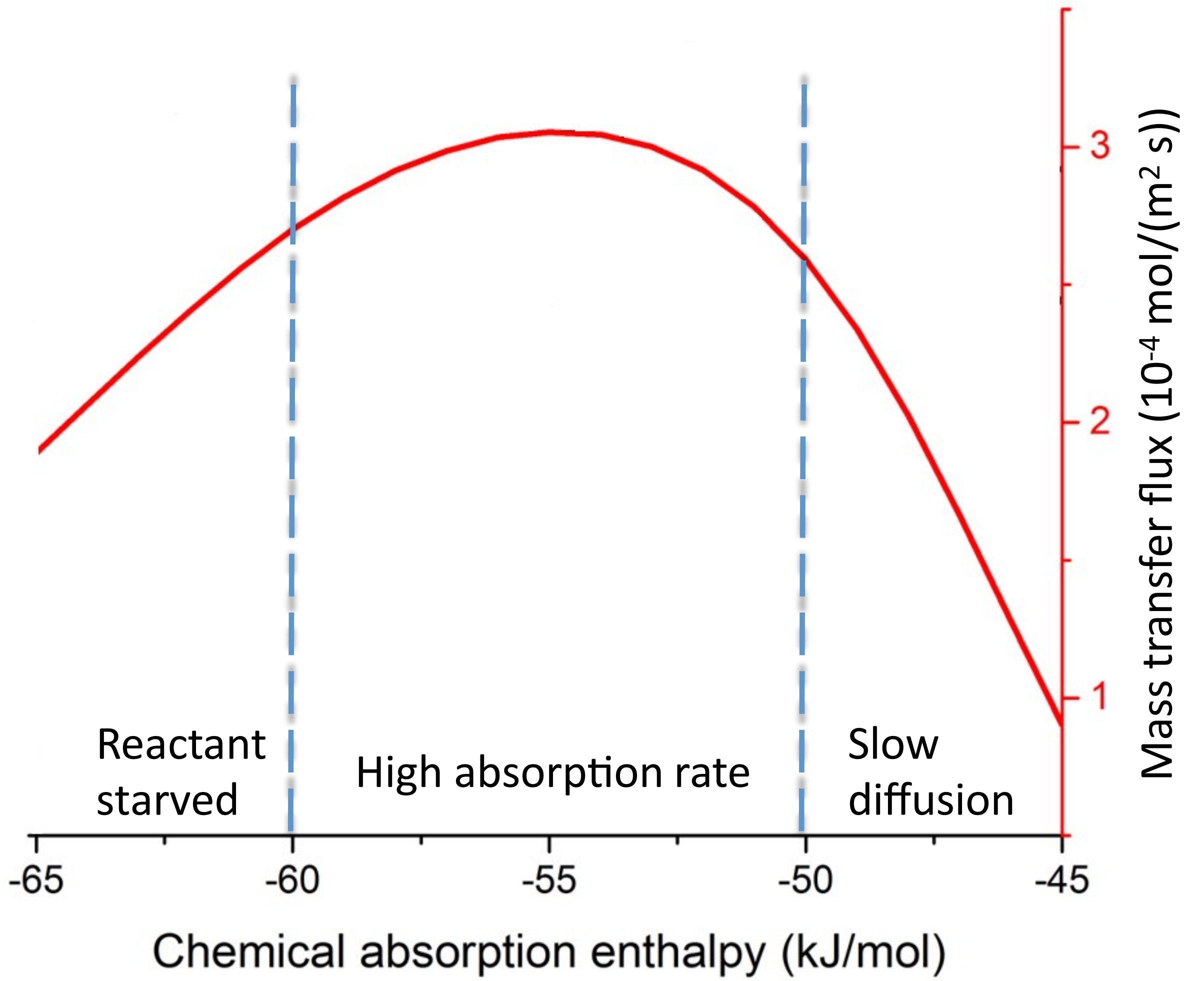


Results
(Chemical absorption enthalpy)

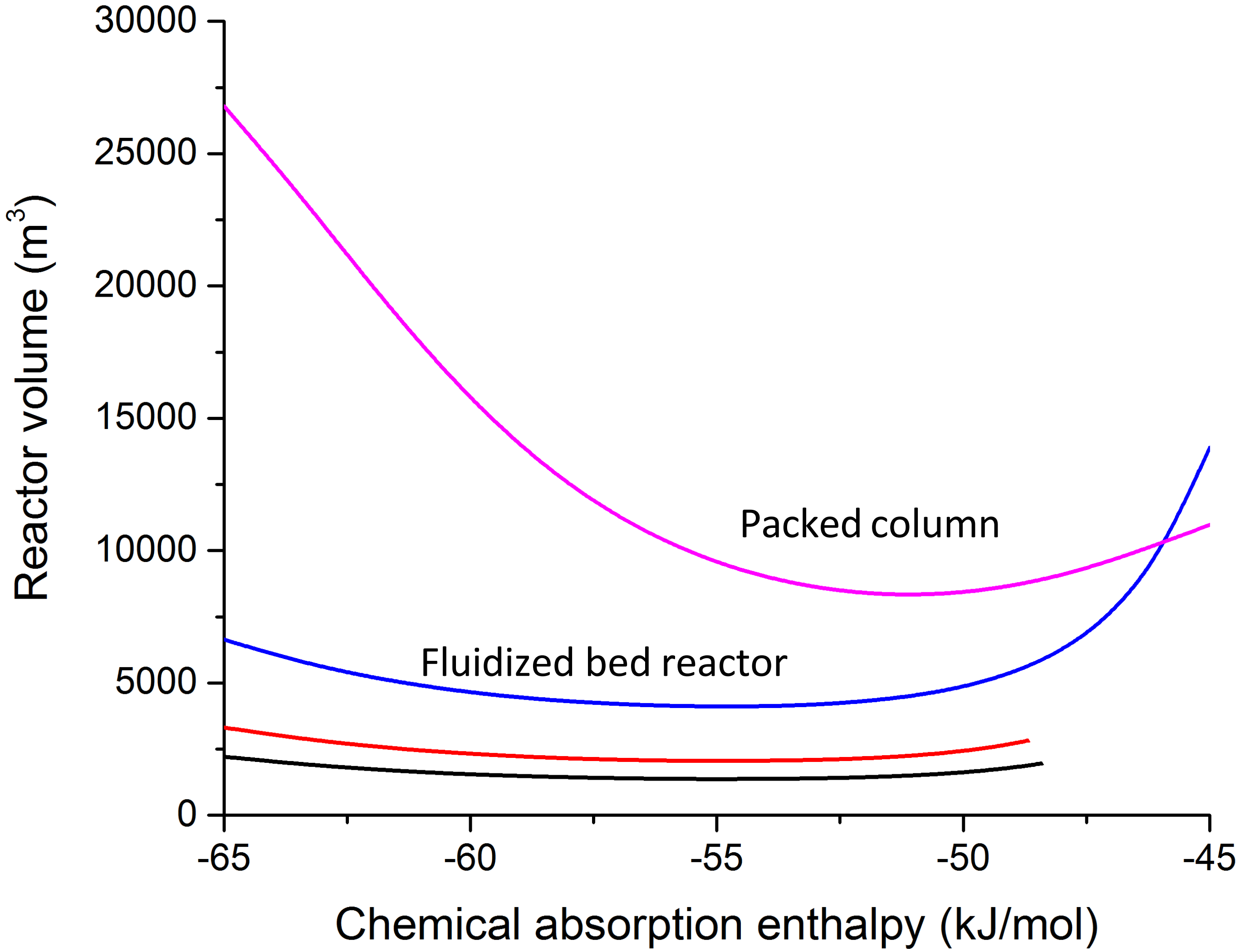
Effect of absorption enthalpy on CO_2 uptake



Effect of absorption enthalpy on mass transfer flux

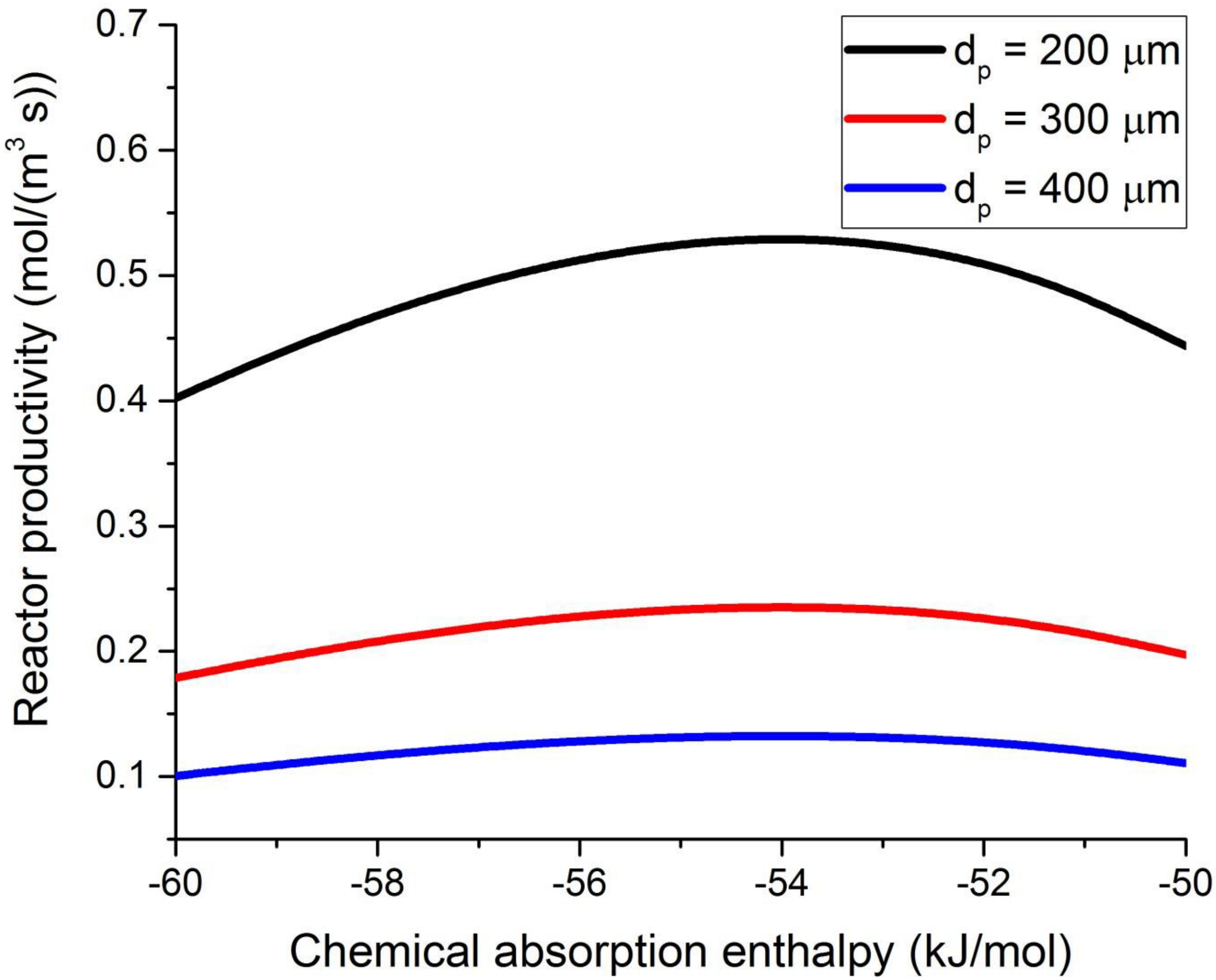


Packed column vs. FB reactor volume

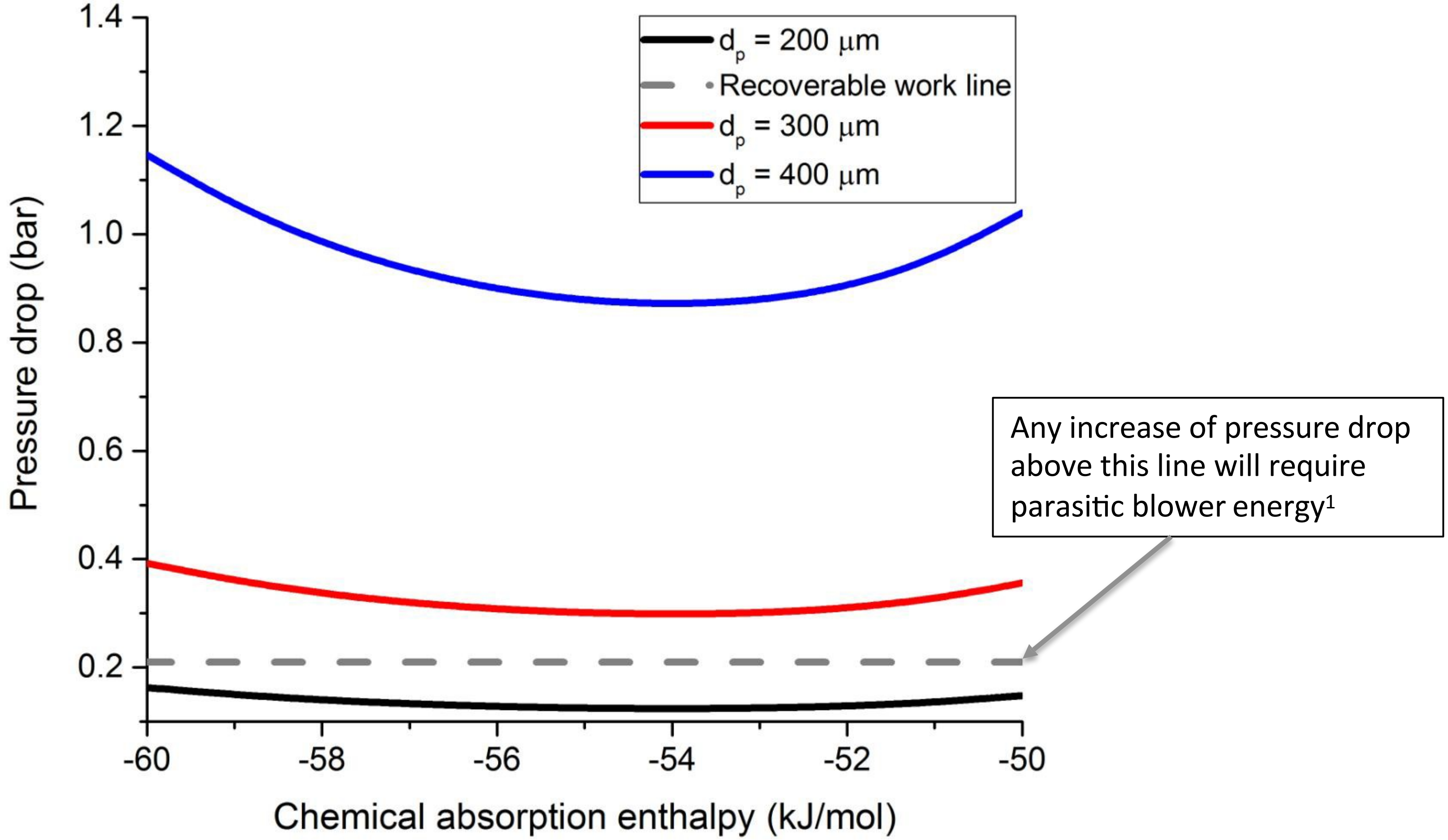


Results
(Capsule diameter)

Effect of capsule diameter on reactor productivity

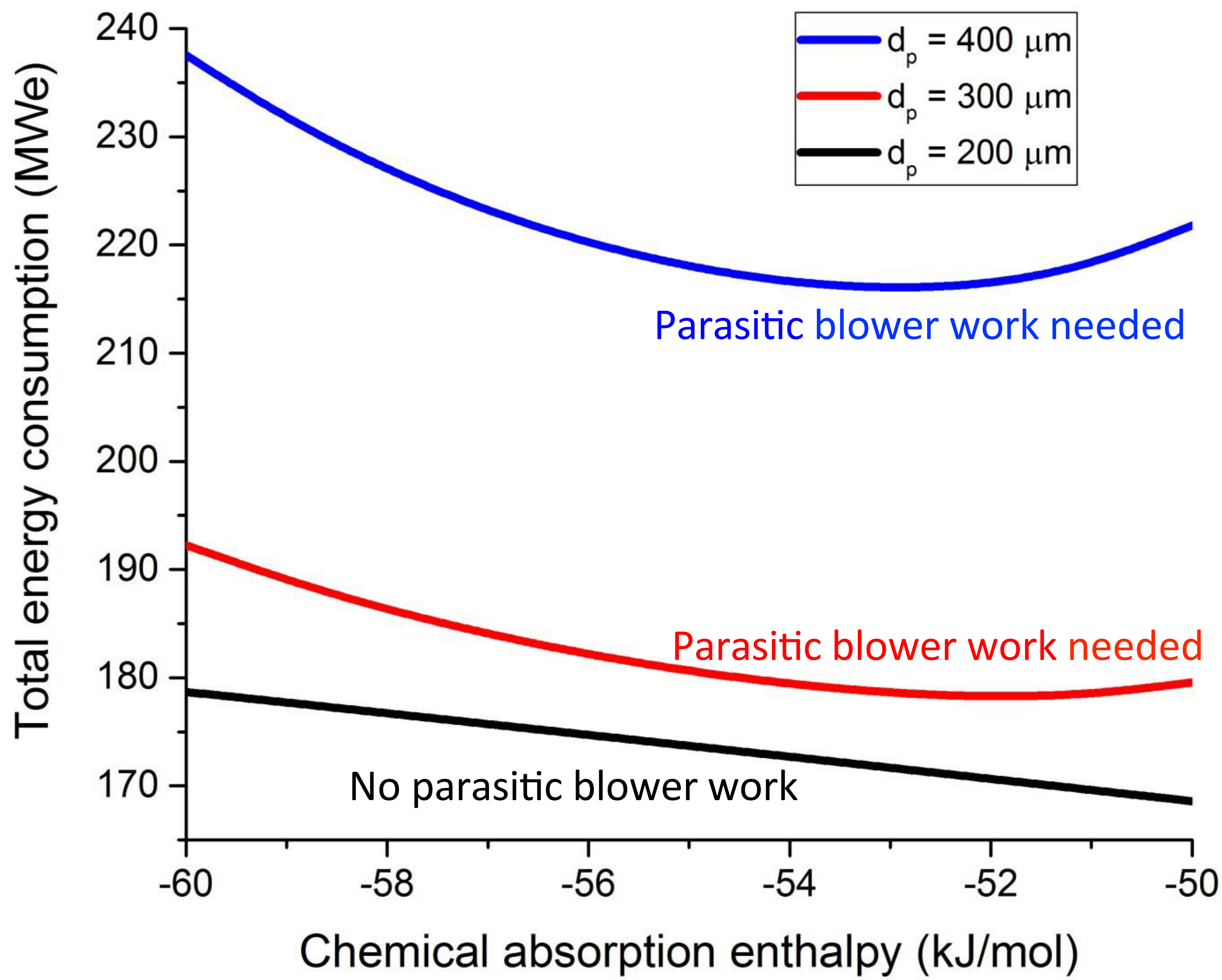


Effect of capsule diameter on pressure drop



1. Yang, Wen-Ching, and James Hoffman. *Industrial & Engineering Chemistry Research* 48 (2008): 341-351.

Effect of capsule diameter on energy consumption



Note : the numbers of energy consumption shown above are not yet optimized.

Concluding remarks

- Too strong or too weak an absorption enthalpy will reduce the mass transfer flux: The optimum absorption enthalpy is around −55 kJ/mol
- A capsule diameter of 200 microns can double the productivity and halve the reactor volume compared with IL-based packed column
- A capsule diameter of 200 microns will reduce the blower work to a level that can be fully recovered from the plant-wide energy system, and thus, offset the high viscosity problem of AHAs

Acknowledgement

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