Bench-scale Development of a Transformational Switchable-hydrophilicity Solvent-enabled Absorption Process for Energy-efficient CO_2 Capture and Fixation

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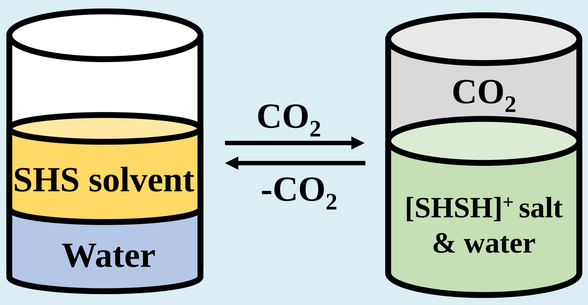
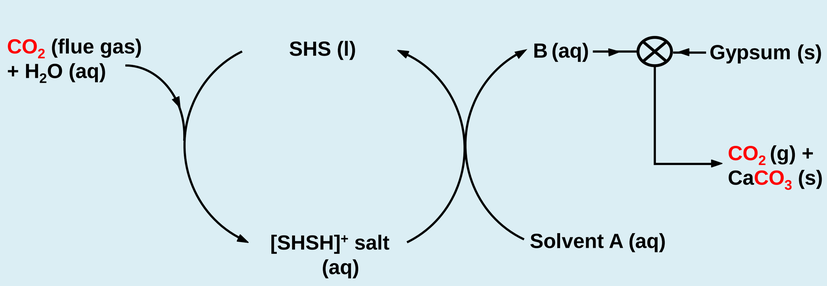
MOTIVATION

A new switchable-hydrophilicity solvent (SHS) based post-combustion CO_2 capture technology enabling both the carbon capture and fixation can significantly improve the energy efficiency of CO_2 capture process



SHSs are classified as a family of new-generation phase-change solvents



CO_2 absorption capacity is doubled due to this unique cycle design

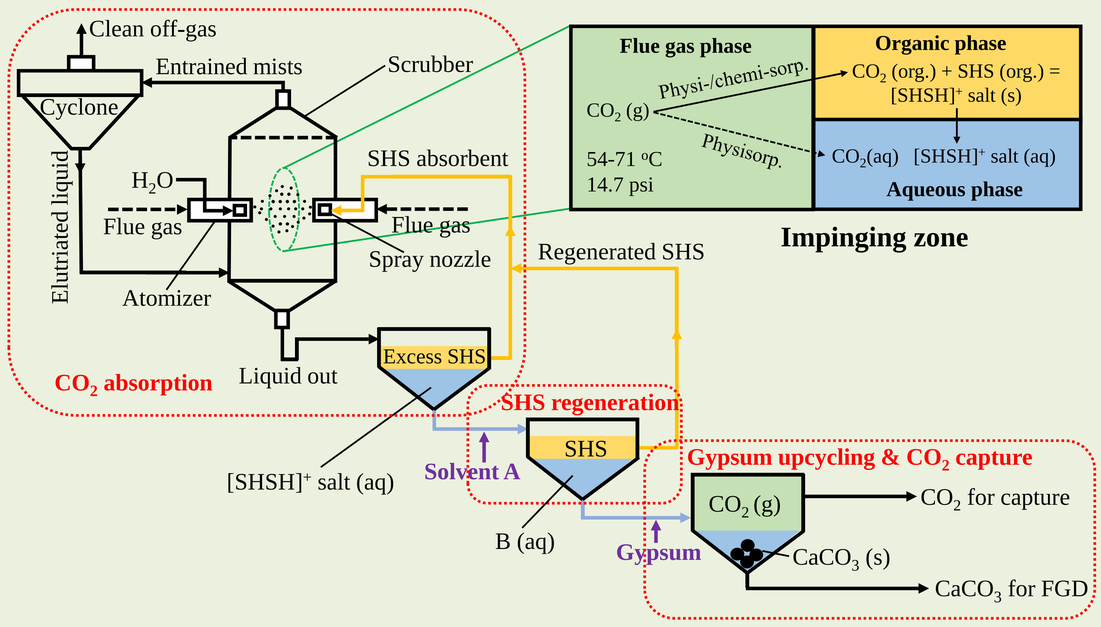
GRAND CHALLENGES IN CCS WITH CONVENTIONAL AMINE ABSORBENTS

- Fast amine solvent loss rate due to thermal and oxidative degradation
- High energy penalty for rich solvent regeneration
- Conventional carbon emissions mitigation strategies generally suffer up to 40% or more of the energy output of a coal-fired power plant

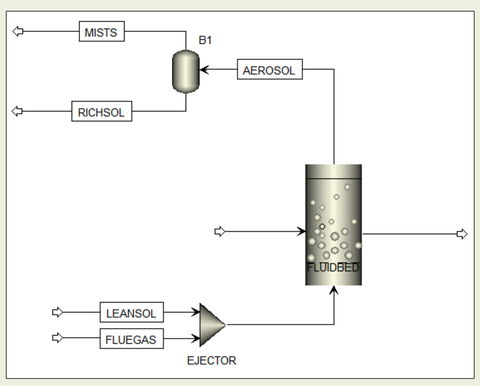
OVERALL OBJECTIVES

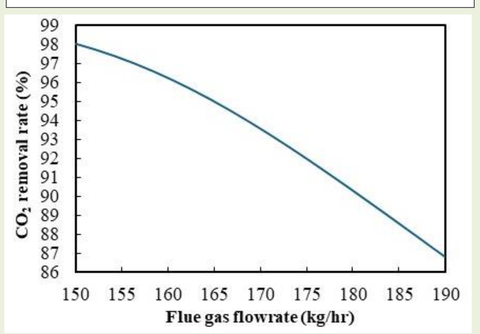
- ❖ Design a tandem carbon capture process to improve energy efficiency
- ❖ Build a gas-liquid impinging scrubber with fast interfacial mass transfer rate
- ❖ Regenerate rich solvent at ambient or mild temperatures
- ❖ Offer a sustainable approach to effective waste valorization

CARBON CAPTURE AND CONCURRENT GYPSUM WASTE UPCYCLING



Carbon capture and fixation are accomplished by three key steps





- ❖ Greatly broadeded accessibility window for biphasic solvent selection
- ❖ Fast CO_2 absorption kinetics via new scrubber
- ❖ Inter-tip spacing has a little effect on CO_2 absorption kinetics
- ❖ No frothing issues during absorptions
- ❖ Total C content partitioned both in the excess and regenerated amine phases account for < 5%
- ❖ ~90% CO_2 removal rate could be achieved at 2 GPM of solvent flowrate and 2.85 m³/min of flue gas flowrate

KEY INNOVATIONS

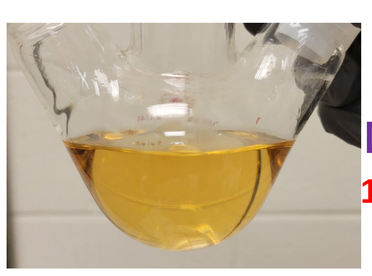
- ❑ **Absorption reaction/extraction coupling to break up chemical equilibrium limitations**
- ❑ **Low-temperature rich solvent regeneration to mitigate solvent makeup rate, equipment corrosion, and energy consumption**
- ❑ **Gypsum waste upcycling to limestone sorbent to enable direct use of low-grade coal**
- ❑ **Innovative design and integration of sub-systems to deliver energy-efficient carbon management process**

CO_2 ABSORPTION

Solvent	Amine content (M)	Absorption T (°C)	Absorption time (min)	Aqu. vol. (%)	Aqu. CO_2 loading capacity (mol/kg)
SHS-1	3.5	40	10	60.40	1.039
			20	72.45	1.605
			30	73.58	2.040
			60	76.27	2.533
MEA	5.0	40	10	100	0.615
			20	100	1.226
			30	100	1.981
			60	100	2.211

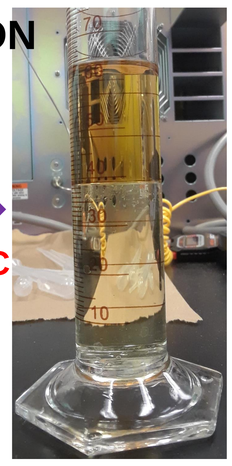
- ✓ Aqueous-phase carbon loadings are enriched due to liquid-liquid phase separation (LLPS)
- ✓ Aqueous-phase volume increases over time
- ✓ CO_2 absorption capacity shows advantage over 30 wt.% MEA solvents under the same operating conditions

RICH SOLVENT REGENERATION



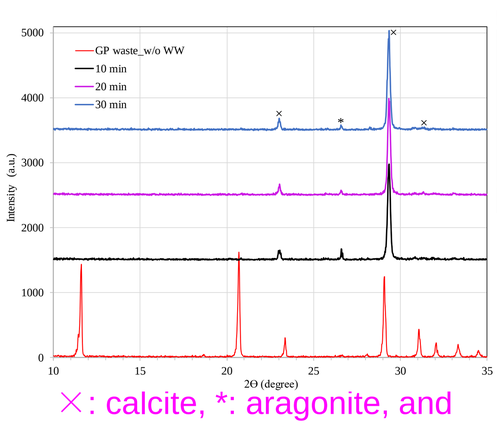
Regeneration

10 min @ 65 °C

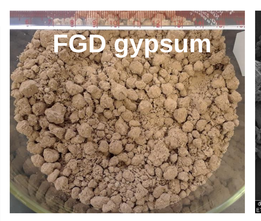


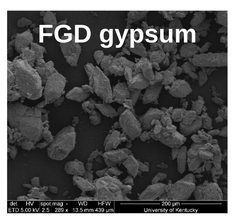
- ✓ After regeneration, aqueous phase accounts for 60.6 vol.%
- ✓ Aqueous-phase carbon loading capacity takes up 97.7%
- ✓ Regenerated solvent behaves like a fresh chemical
- ✓ Spontaneous LLPS promotes a deep regenerability of rich solvents under mild operating conditions

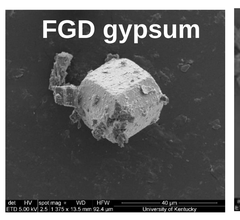
GYPSUM UPCYCLING INTO LIMESTONE

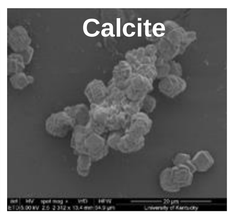


×: calcite, *: aragonite, and WW: water wash



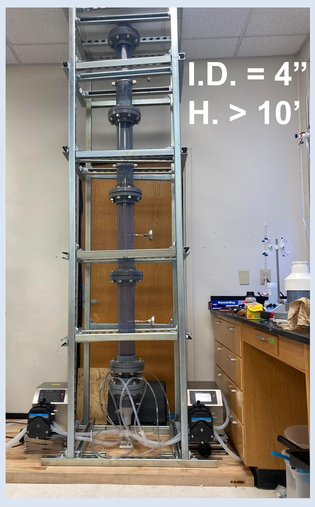






- ✓ FGD gypsum was fully transformed into well-faceted calcite within 10 min at 40 °C
- ✓ 1 kg of FGD gypsum was completely converted into calcite within 10 min at 60 °C

KEY COMPONENTS OF CO_2 CAPTURE PROCESS



CARBON CAPTURE PERFORMANCE METRICS

Metrics	Values
CO_2 loading capacity at 40 °C	≥ 2 mol/kg
Overall cyclic CO_2-equivalent loading capacity	≥ 1.8 mol/kg
CO_2 absorption time	≤ 10 min
ER of rich solvents at $T \leq 65$ °C	≥ 95%
Regeneration reaction time	≤ 10 min
Gypsum waste purity	≥ 95%
Gypsum conversion efficiency	≥ 95%
Gypsum carbonation time at $T \leq 65$ °C	≤ 10 min
Limestone purity	≥ 95%
CO_2 removal efficiency	≥ 90%
Final CO_2 purity in vapor phase	≥ 95%
Increase in cost of electricity generation	≤ 35%
Overall CO_2 capture cost	~$30/tonne

FUTURE WORK

- Upgrade the whole carbon capture system to realize its full-scale operations at a bench level
- Design and assemble the atomizers to enable an overall solvent flowrate up to 2 GPM
- A 2nd-generation scrubber was built and commissioned in-house with novel packing materials in place
- CO_2 absorption kinetics and overall CO_2 cyclic loading capacity will be further enhanced
- Seamlessly integrate the key three-unit operations to enable continuous operational processes
- More exhaustive TEA of this carbon capture technology will be conducted to gauge its viability for future scale-up

ACKNOWLEDGEMENTS

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