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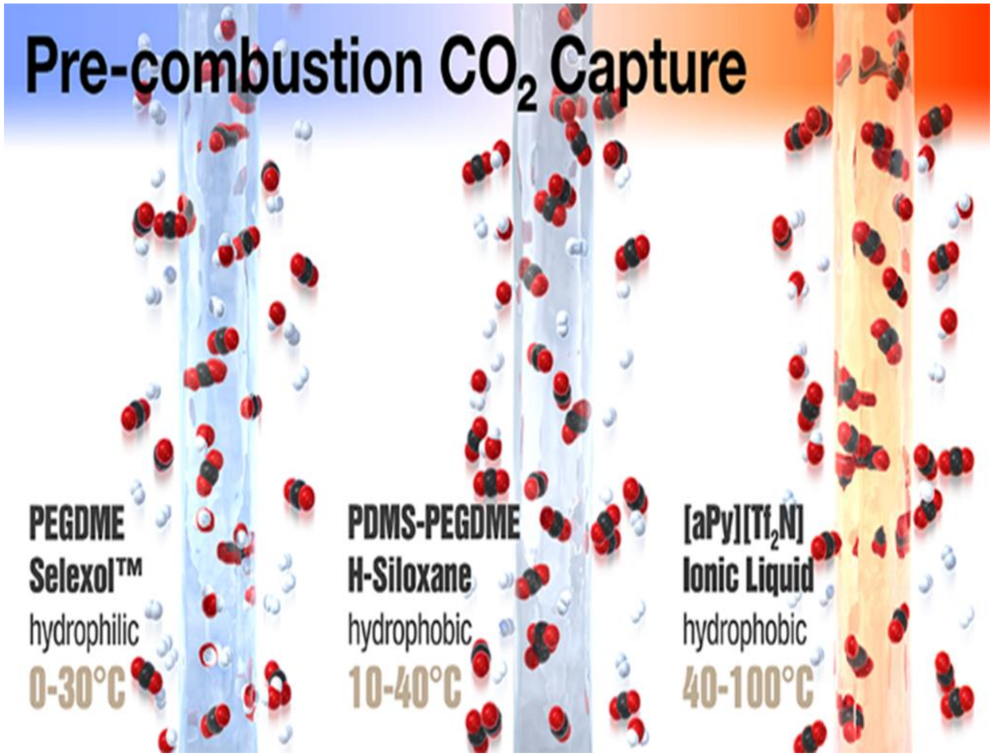

A High Performance Physical Solvent for Pre-Combustion CO_2 Capture

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2018 CO_2 Capture Technology Review

U.S. DEPARTMENT OF ENERGY

Applications for Physical Solvents

Commercial Applications

<u>Tailored markets</u>

- Pre-combustion CO_2 capture at IGCC-CCS
- Generation of H_2 from reformed natural gas
- Generation of H_2 at petroleum refineries
- Adjust CO/H_2 ratio for coal & biomass to liquids
- Remove CO_2 from syngas for ammonia/fertilizer

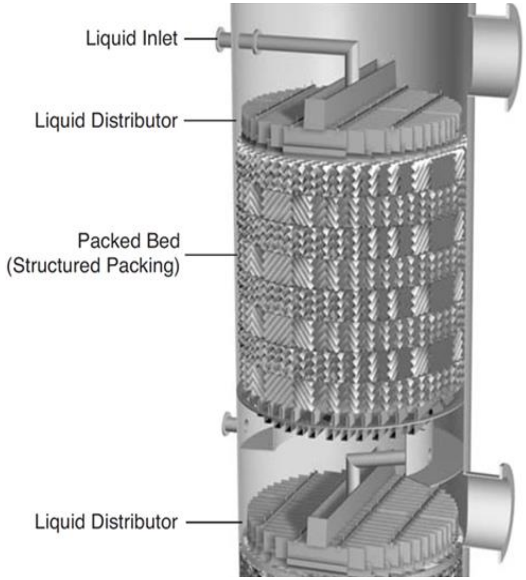
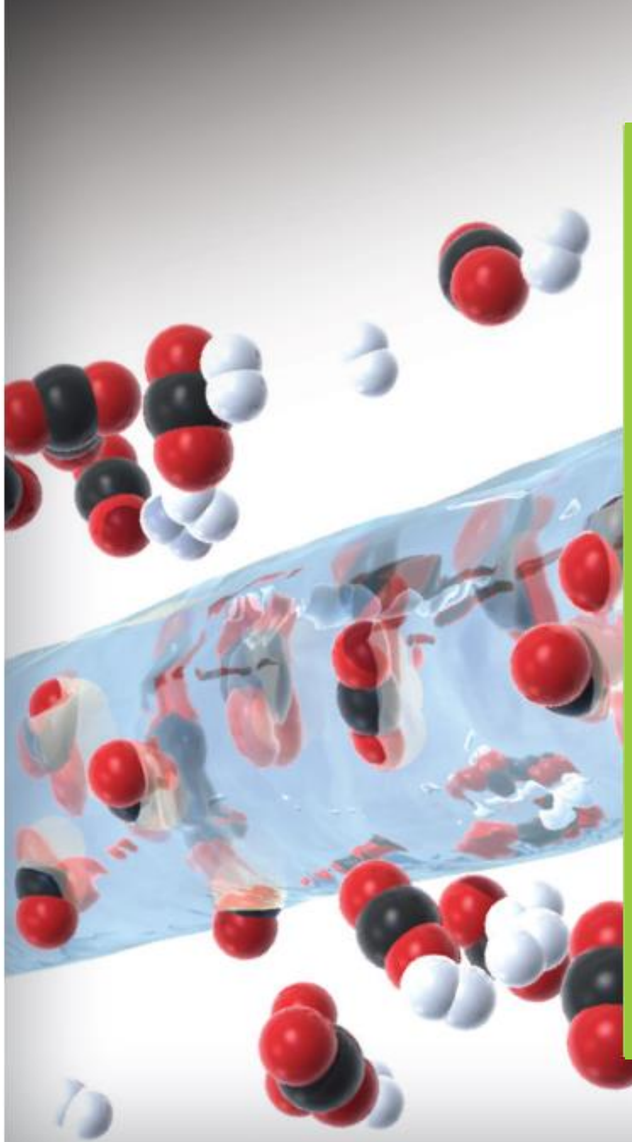


Image from: https://www.globalccsinstitute.com/news/institute-updates/syngas-production-kemper-represents-significant-technical-milestone-transport-integrated-gasifier-power-production

PRE-COMBUSTION SOLVENTS FOR CARBON CAPTURE



Problem:

Commercially operated physical solvents for CO_2 /H_2 separation operate at below room temperature. Hence, they incur a significant electrical cost to chill and can't be regenerated using waste heat.

These solvents are hydrophilic and have high vapor pressure.

Selexol® operates at 10°C (Kemper County, MS)
Rectisol® operates at -10°C (Great Plains, ND)

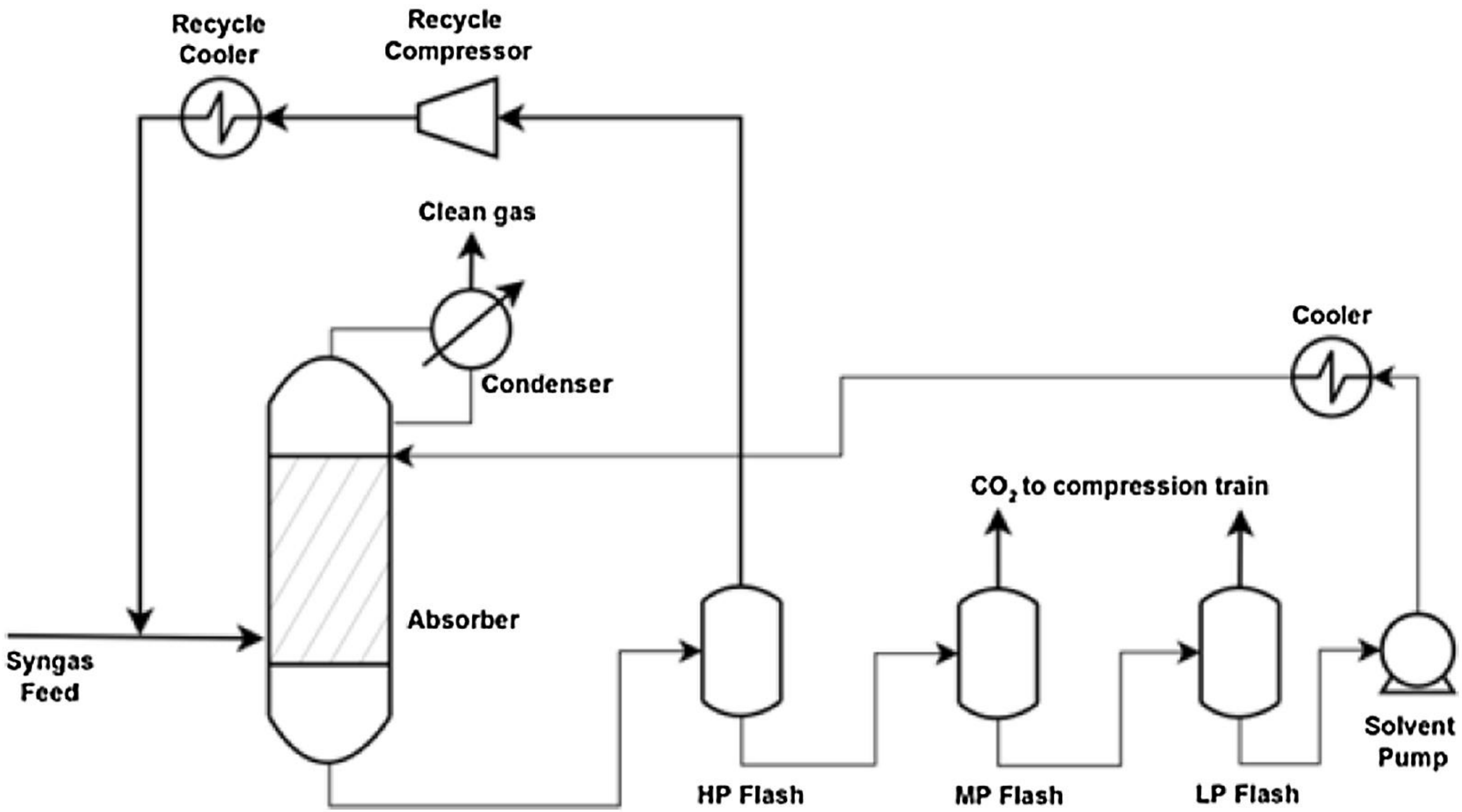
Selexol® (UOP / Dow Chemical) &

Rectisol® (Air Liquide Global E&C Solutions GmbH / Linde AG)

Solution:

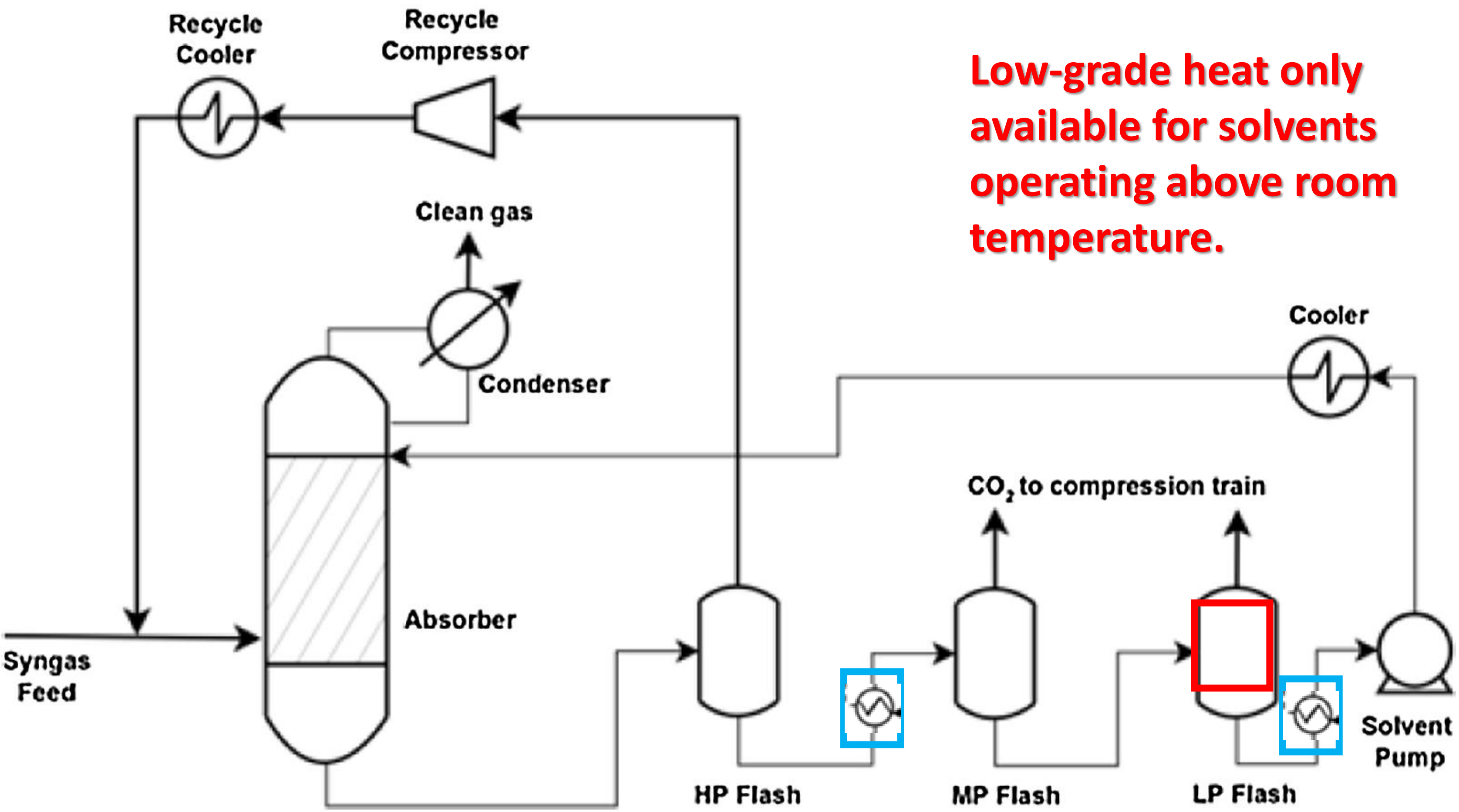
- Find new physical solvents that selectively absorb CO_2 between at temperatures between 25°C and 100°C
- Find solvents that also can be regenerated using waste heat

Baseline Selexol Process Flow Diagram



- In NETL baseline, Selexol® solvent loops at a temperature of 10°C

Potential Process Using Low-Grade Heat

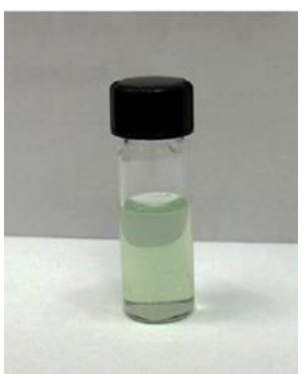


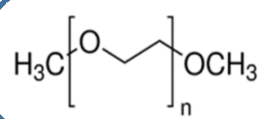
Low-grade heat only available for solvents operating above room temperature.

Pro's & Con's of Selexol vs. Silicone Oils

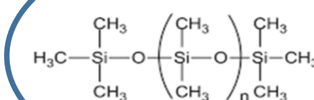
	Processes based on Selexol or Similar Hydrophilic PEG Solvents	Processes based on PDMS or Similar Hydrophobic Solvents
Operating Temperature	**Below room temperature**	**Above room temperature**
Chemical Stability	**Mid**	**High**
Corrosion	**Mid**	**Low**
Cost of the Solvent	**Low**	**Mid**
CO_2 / H_2 Selectivity	**High**	**Low**

PEGDME
fully miscible with water;
Extremely hydrophilic





Integrate Selexol and silicone fluid into novel, hydrophobic solvents: Hybrid PDMS (HPDMS)

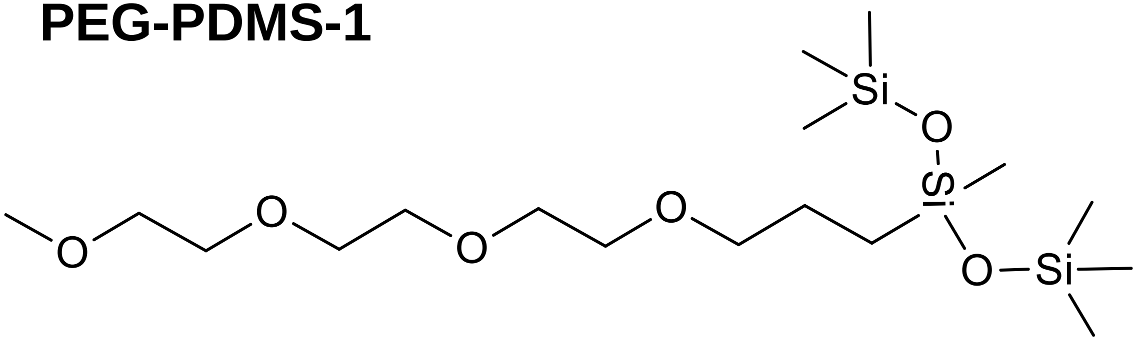


PDMS
immiscible with water, even at 120C and 10000 psi; separates quickly after shaking;
Extremely hydrophobic

PEG-PDMS solvent#1

Attempt to incorporate best of both systems

PEG-PDMS-1



Siloxane functionality resembling PDMS: hydrophobicity and improved gas selectivity

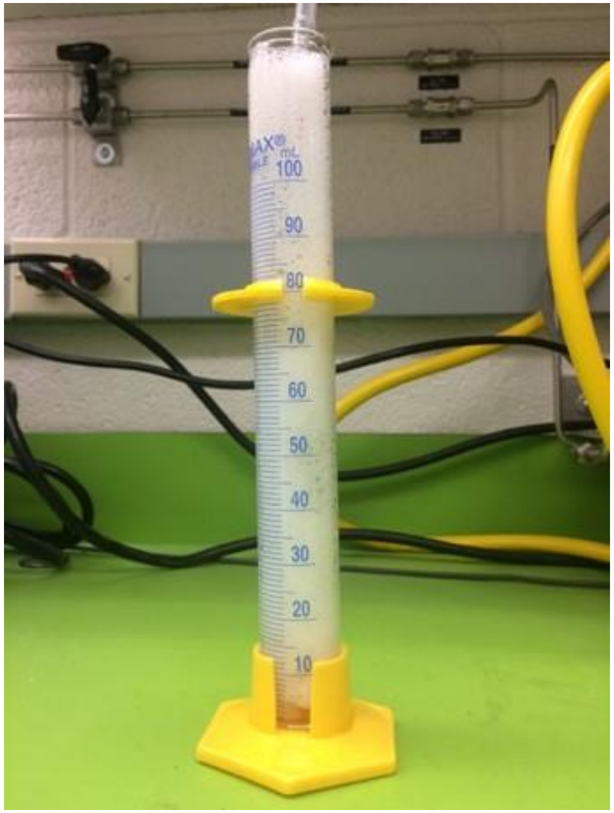
PEG functionality resembling Selexol: to maintain good CO_2 uptake capacity

Hybrid structure - improve CO_2/H_2 selectivity, while maintaining good CO_2 solubility in a *hydrophobic* solvent system

"High performance hydrophobic solvent, carbon dioxide capture"
[Patent 9,643,123 (issued May 9, 2017)]

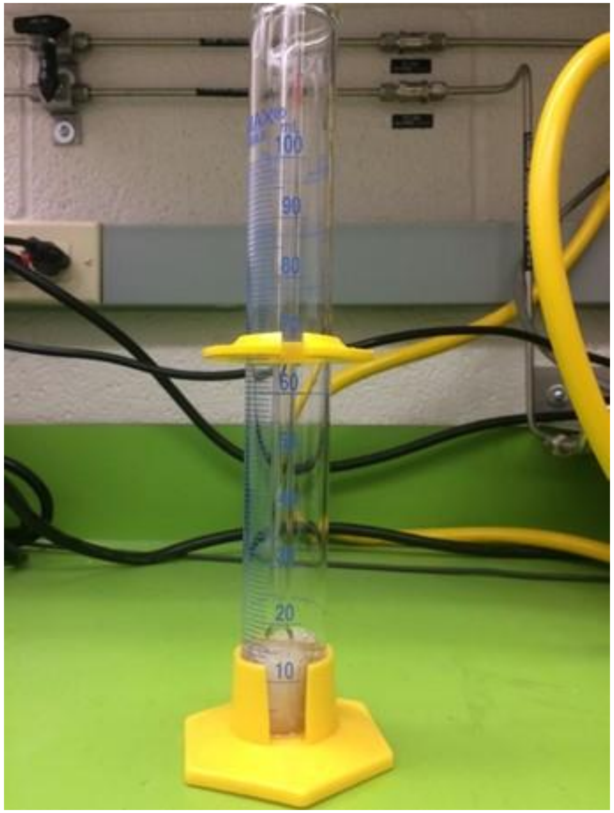
Foaming issue has been addressed

PEG-PDMS-1



Severe foaming

PEG-PDMS-3



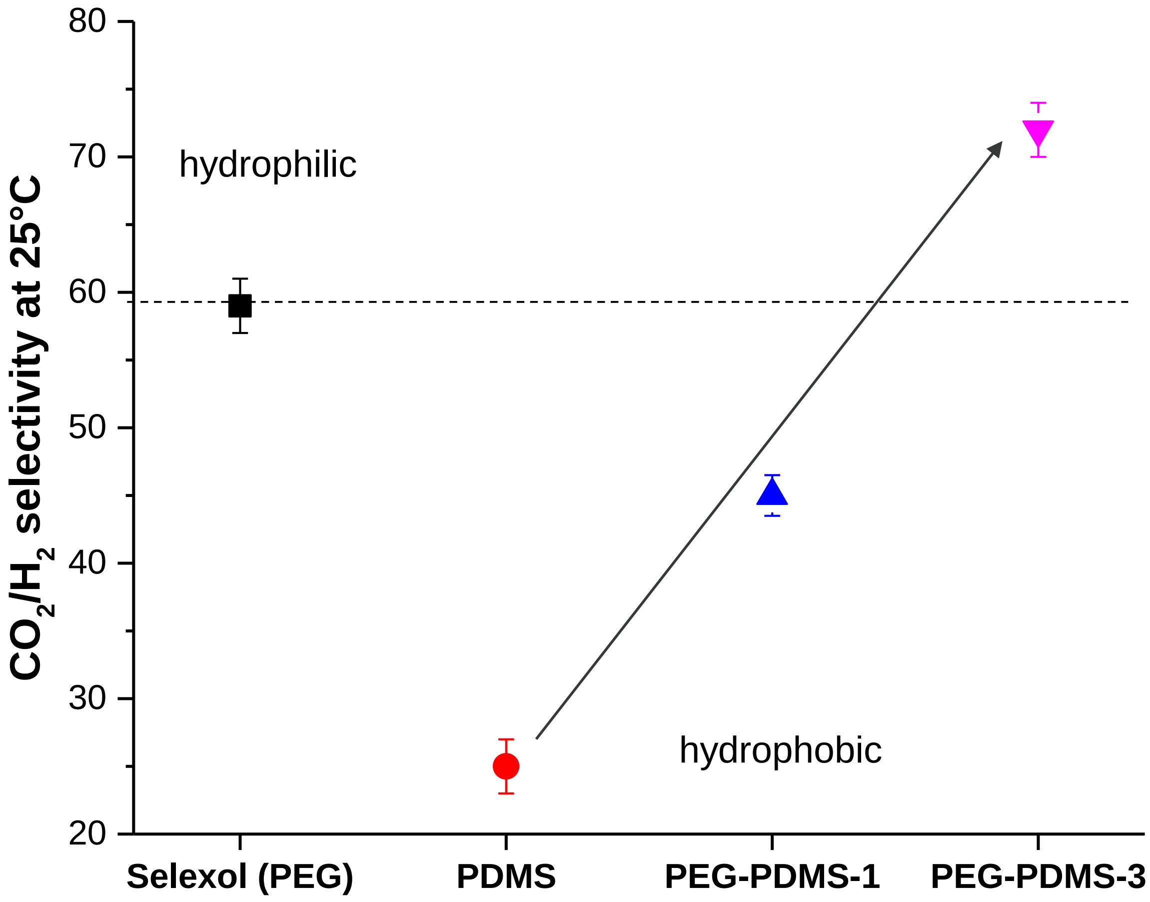
No foaming

Physical Properties

	MW, g/mol	density, g/mL at 25°C	viscosity, cP at (X°C)	CO_2/H_2 at 25°C	CO_2/H_2 at 40°C	foam?
Selexol*	280	1.03	**10.6** (10°C)	59 ± 2	40 ± 2	no
PEG-PDMS-1	427	0.935	**3.9** (30°C)	45 ± 1	33 ± 1	yes
PEG-PDMS-3	620	0.987	**8.1** (40°C)	**72 ± 2**	**60 ± 1**	**no**

- PEG-PDMS-3 is the best overall performing precombustion physical solvent known in the literature for CO_2 capture
- Synthesis procedure is simple and scalable, and raw feedstocks are moderately priced
- Allows for CO_2 capture at above room temperature and allows for waste heat to be used to regenerate the solvent
- = Selexol surrogate tested at NETL/RIC CSTR
  Univar (Bunola, PA)

PEG-PDMS Solvents
progress of crucial characteristics



* =Selexol surrogate (sold by Univar) tested at NETL/RIC's CSTR

CO_2/H_2 selectivity measurements performed by Lei Hong on CSTR at NETL using dry solvents at 25°C

Low Moisture Uptake

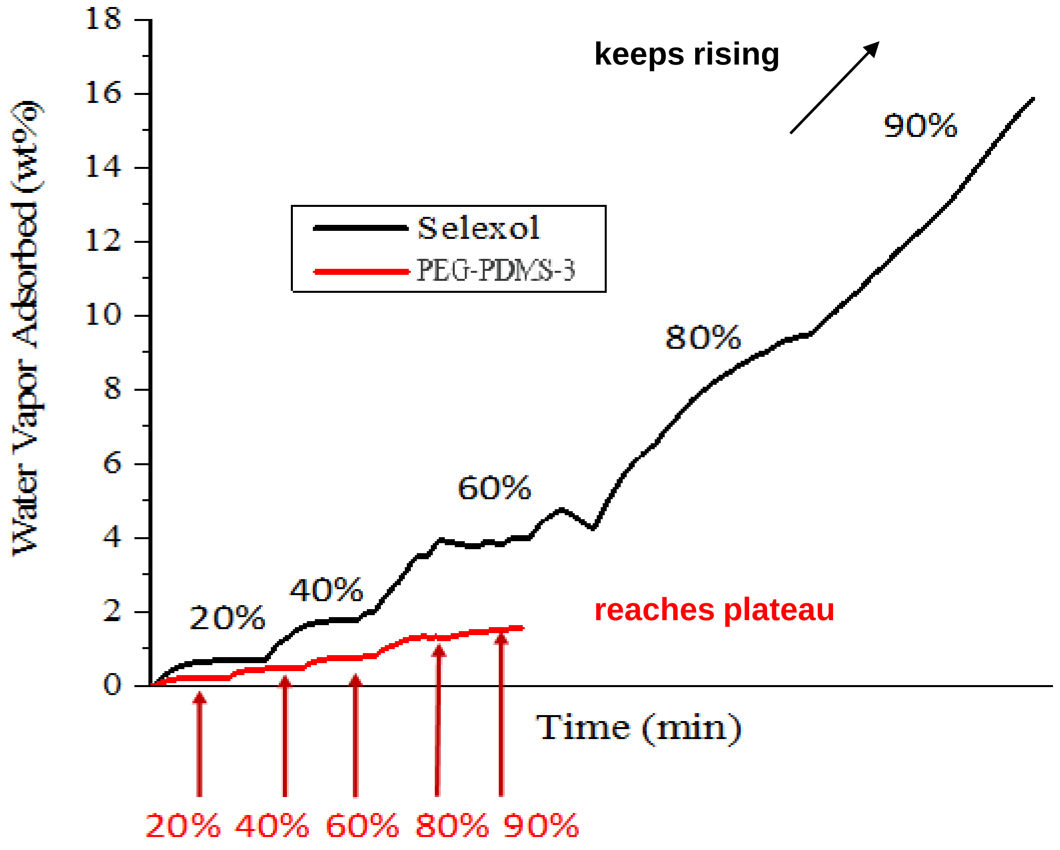
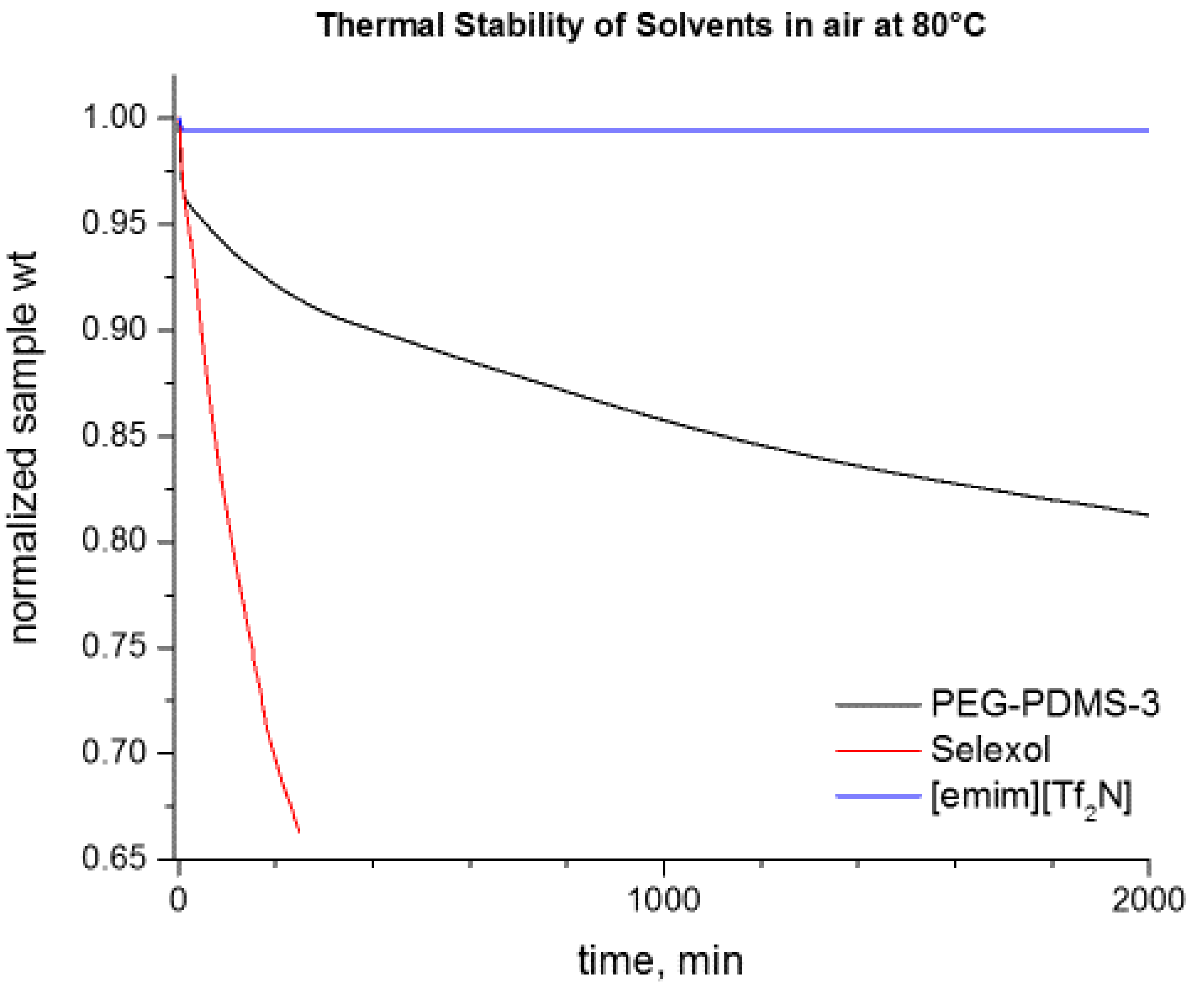


Figure 2: Comparison of water vapor absorption for PEG-PDMS-3 and Selexol surrogate (Univar.) Sample temperature at 25°C. Feed gas is a blend of wet and dry N_2. The percent of wet N_2 in the feed stream at different points in the curves is indicated by the numbers on the plot. Data was collected on the Hiden IGA. Note: Selexol surrogate does not approach saturation under high humidity conditions

- **PEG-PDMS-3 absorbs significantly less water vapor than Selexol***

Low Evaporation Rate for PEG-PDMS-3



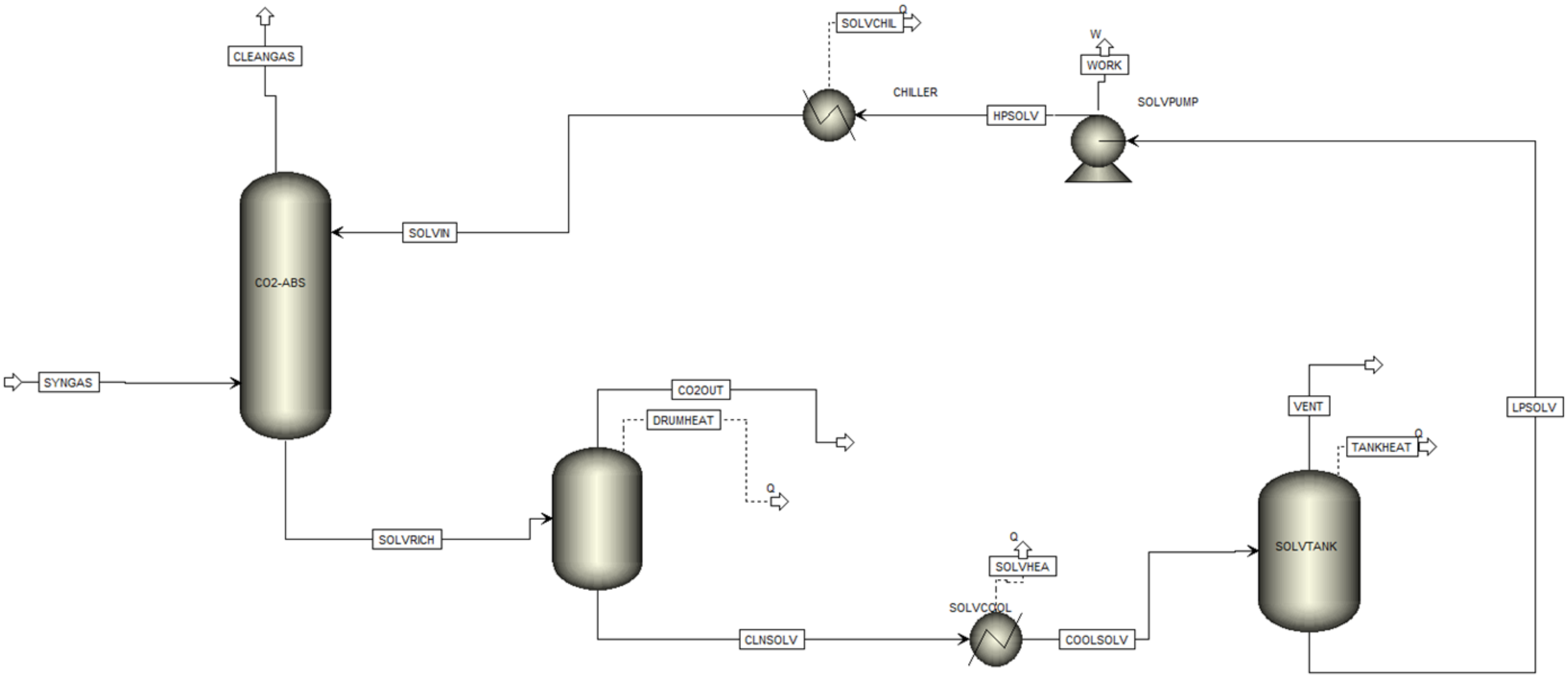
- Vapor pressure of PEG-PDMS-3 is significantly below Selexol*

Future Testing of PEG-PDMS-3 at UND EERC Gasifier

- Goal: Test both PEG-PDMS-3 and Selexol® under real syngas generated at either a fluidized or entrained flow gasifier
- Test scale = 60 liters of solvent
- Absorption at 10-40℃
- Regeneration at 10-80℃

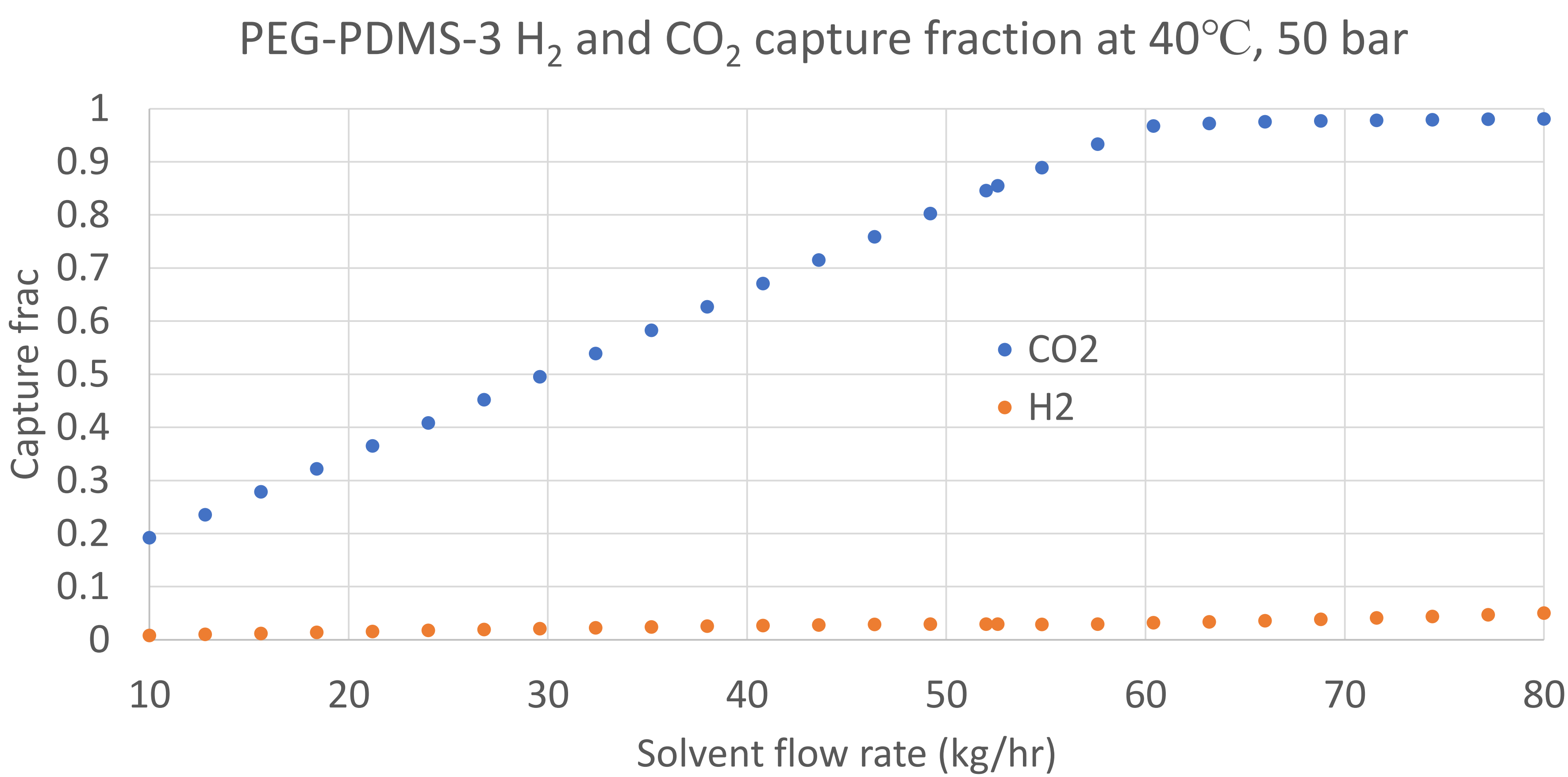
Gasifier Name	Type	Scale	Feed Rate, lb/hr	Syngas Production, scfm	System Pressure, psi	Gasifier Nominal Temperature, °F	Warm-Gas Cleanup Capability
CFBR	Fluidized bed	Bench	4	8 on air 1.5–2 on O_2	150	1525 (metal reactor)	Full stream
TRDU	Transport reactor	Pilot	200–500	400 on air 250 on O_2	120	2000 refractory-lined	Slipstream, 5%
EFG	Entrained flow	Bench	4–16	16–20	300	2730 refractory-, ceramic-lined	Full stream
HPFBG	Fluidized bed	Bench	4–20	30–40	600–1000	1600 to 1800 depending on operating pressure (metal reactor)	Full stream

Aspen Plus Modeling of UND EERC



- **Absorption column at UND EERC was modeled as a RadFrac Rate Based Separator in Aspen Plus. Kinetics were estimated using experimental data from the facility.**

Aspen Plus Results for UND EERC Conditions

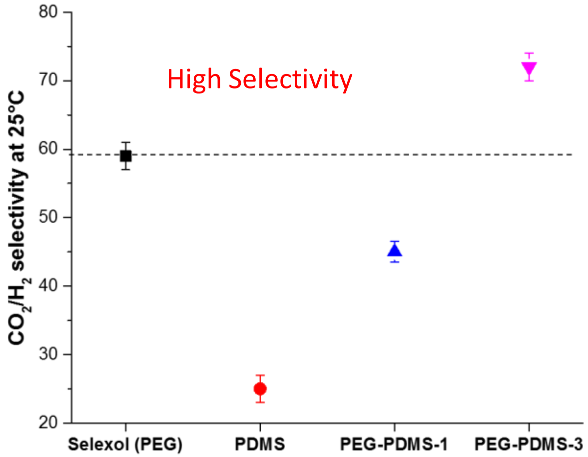


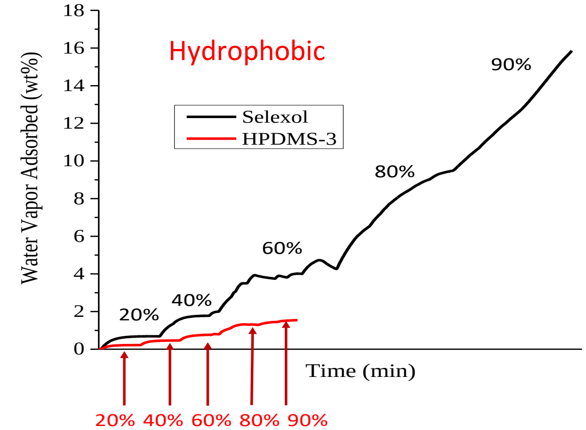
- **Predictions for CO_2 and H_2 uptake into PEG-PDMS-3 as a function of solvent flow rate**

Conclusions

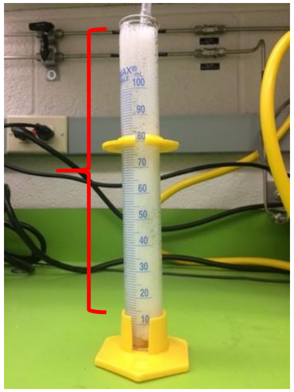
PEG-PDMS-3

- Higher CO_2/H_2 selectivity than Selexol*
- Hydrophobic
- No foaming
- Low vapor pressure
- Low evaporation





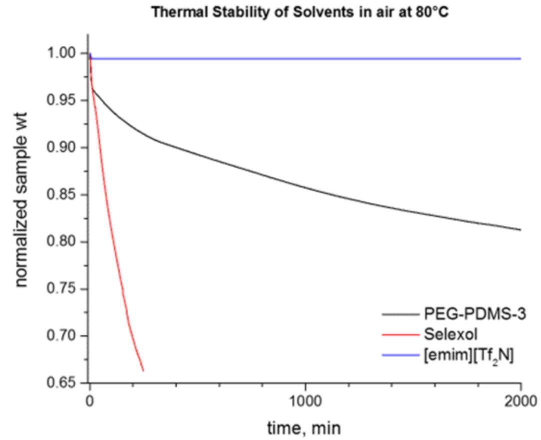
PEG-PDMS-1



severe foaming

PEG-PDMS-3

no foaming



Lower Vapor Pressure = Lower Evaporation

Acknowledgements

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