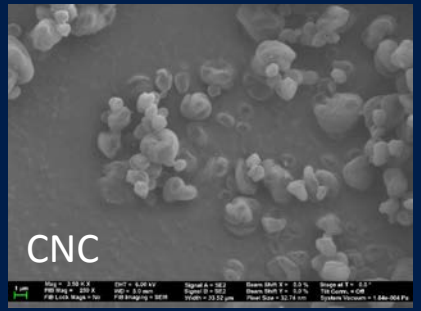
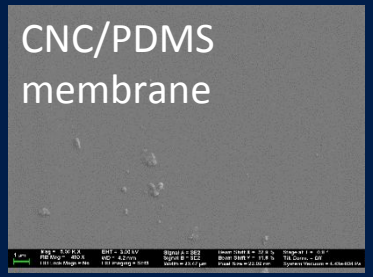
2023 PDC Nanomaterials Forum 2023





Cellulose Nanocrystals (CNCs) as additives in polymeric membranes for water vapor and air separation

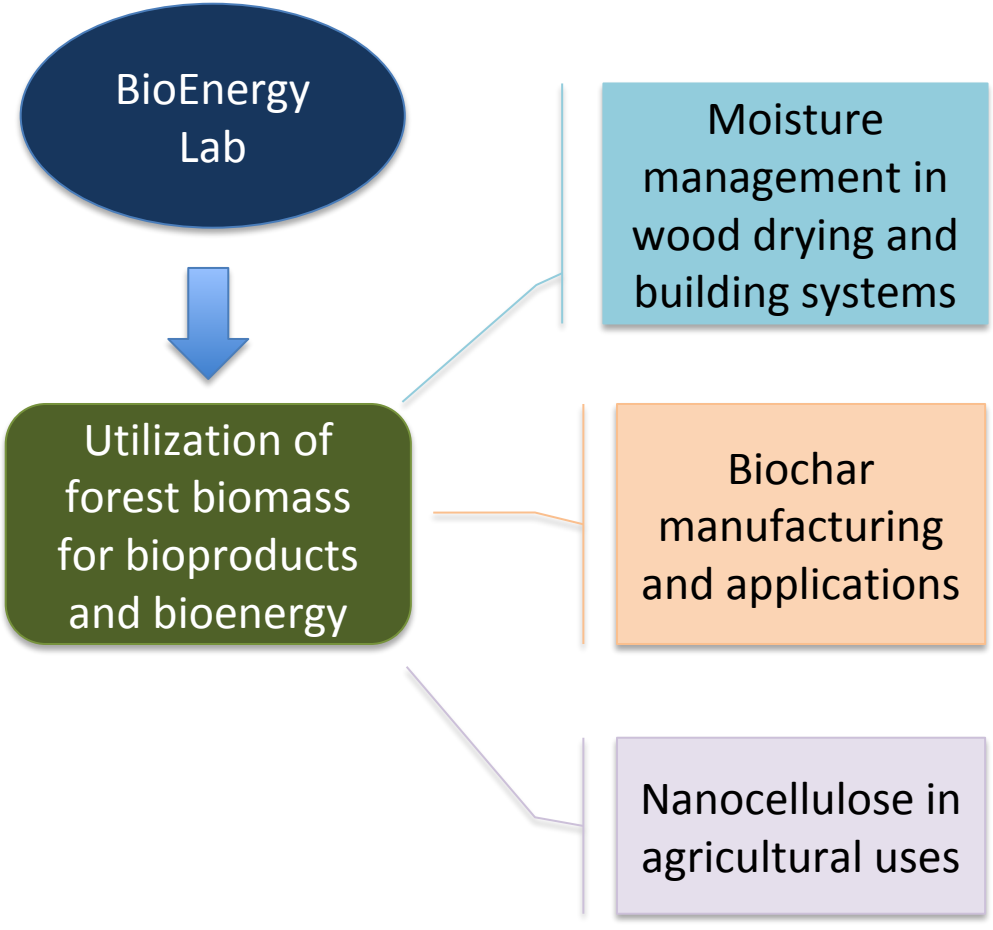
Dr. Ling Li
Dr. Nasim Alikhani
BioEnergy Lab
School of Forest Resources

Dr. Jinwu Wang
Engineered Composites Science Group
USDA FS Forest Products Lab

Dr. Naveenkumar Rajendiran
Statistics, LCA, and Economics Research Group
USDA FS Forest Products Lab

August 24, 2023

BioEnergy Lab

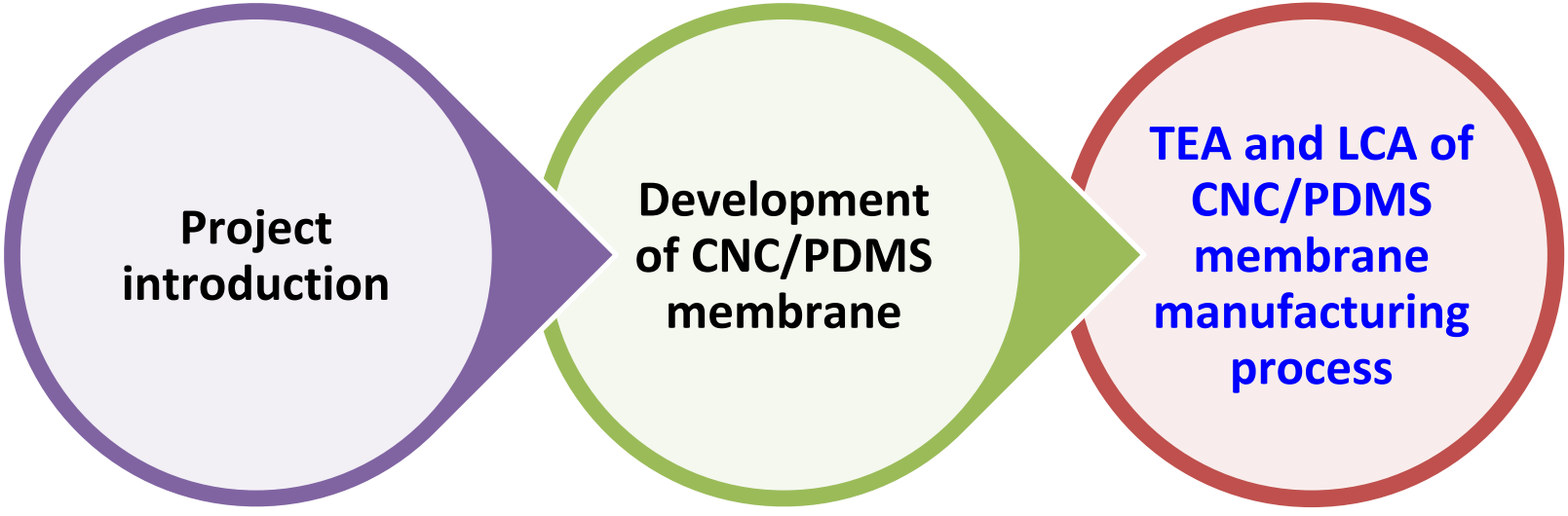


- **<u>Moisture selective membrane for air dehumidification *(Collaborators: FPL)*</u>**
- Hygrothermal performance of wood fiber insulated panels *(Collaborators: ASCC, FPL, TimberHP, & OPAL)*

- Upcycling waste biochar from CHP plants for soil applications
- Biochar for environmental mitigation *(Collaborators: Zhang plant physiology lab (SBE); Schattman Agroecology Lab (SFA))*

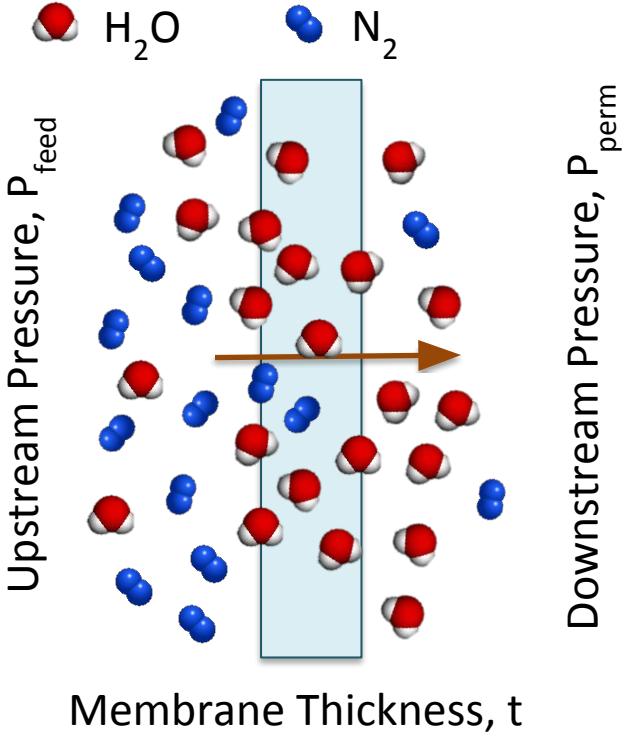
- Nanocellulose coating for perishable fruits and plant leaves *(Collaborators: Zhang plant physiology lab (SBE); Lu Wang (UTK))*

Outline


Project introduction
Development of CNC/PDMS membrane
TEA and LCA of CNC/PDMS membrane manufacturing process

Introduction

Dense polymeric membrane for water vapor/gas separation



Solution-diffusion model:

1) Sorption on upstream side
2) Diffusion down partial pressure gradient
3) Desorption on downstream side

$$Flux\ of\ A \equiv J_A = \frac{P_A\left(P_{feed,A} - P_{perm,A}\right)}{t}$$
$$[A = H_2O\ or\ N_2]$$

$$\text{Permeability of A} \equiv P_A = D_A \times S_A$$

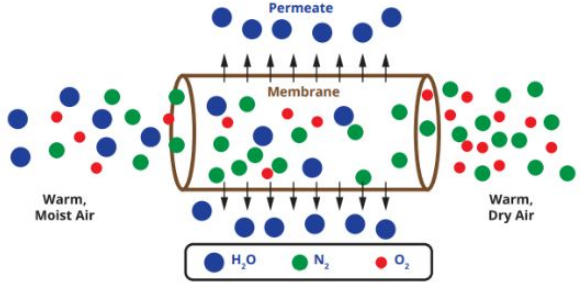
D_A= Diffusion coefficient of A

S_A=Solubility coefficient of A

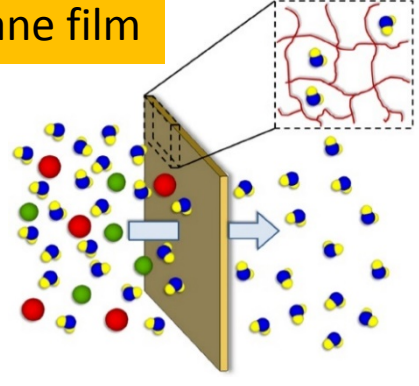
Introduction

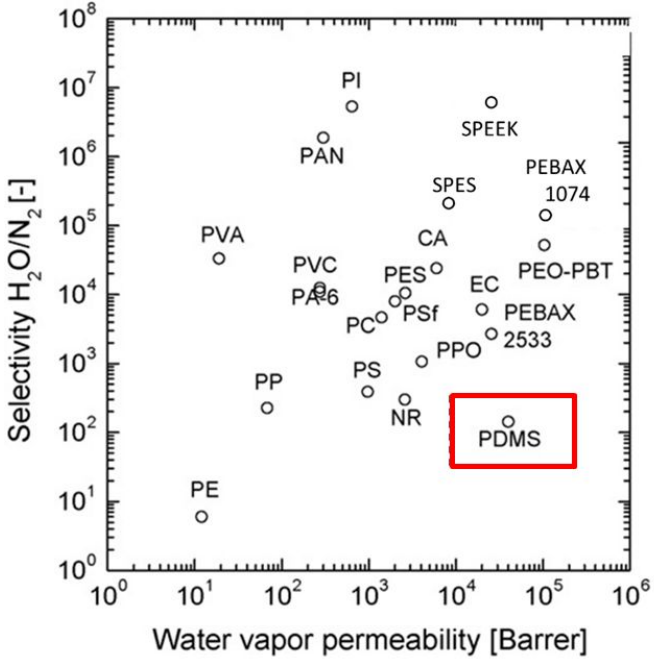
Dense polymeric membrane for water vapor/air separation

Hollow fiber membrane



Membrane film





(Ref: Sijbesma and Nymeijer, 2008)

Polydimethylsiloxane (PDMS)

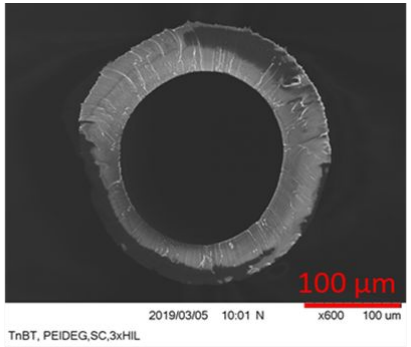
- Permeability of H_2O: **36,000** Barrer
- Selectivity of H_2O/N_2=129

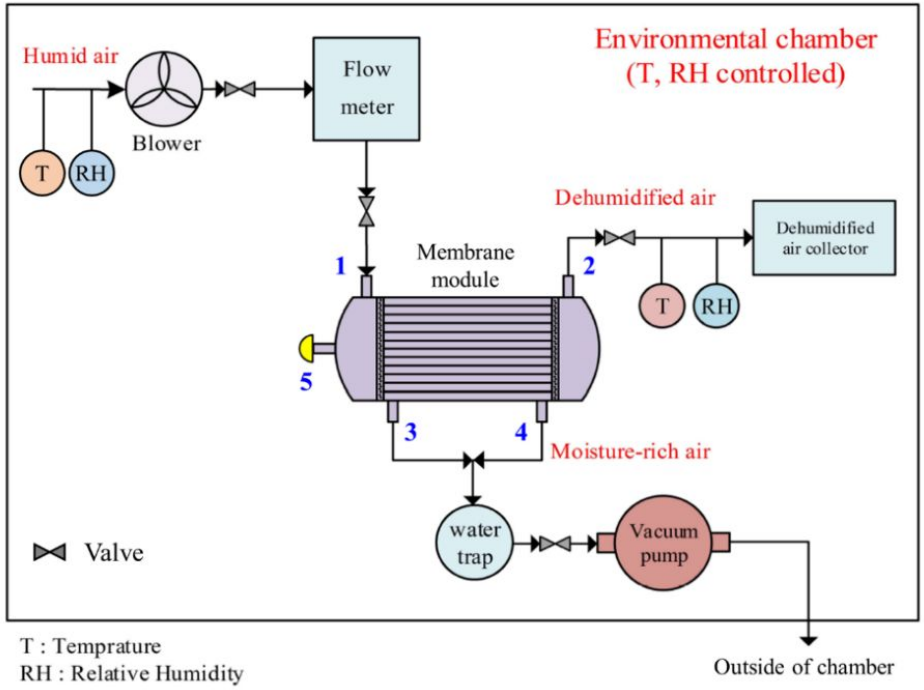
Introduction

Lab-scale membrane system: Efficiency of water vapor removal from air

Factor	Level		
	Low	Medium	High
Temperature , °C	25	35	45
Initial RH, %	65	75	85
Air flow rate, ml/min	600	800	1,000
Vacuum Pressure, inch-Hg	20	23	26

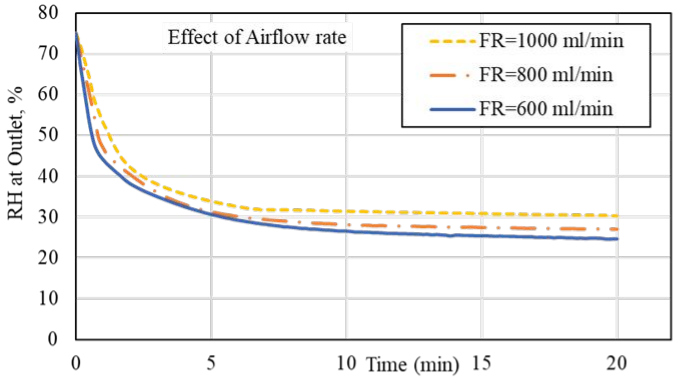
$$Efficiency(\%) = \frac{(RH_{in} - RH_{out})}{RH_{in}} \times 100$$



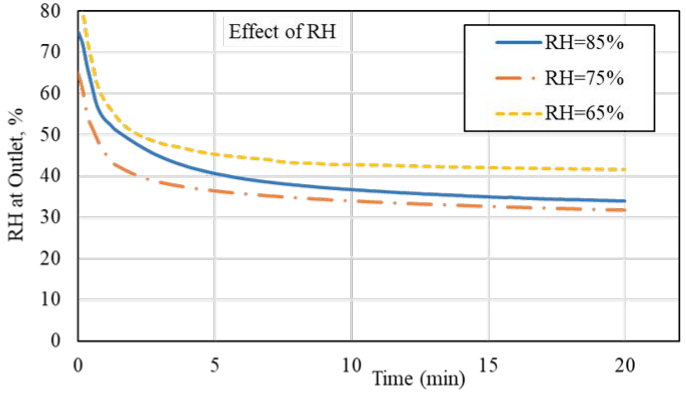


Introduction

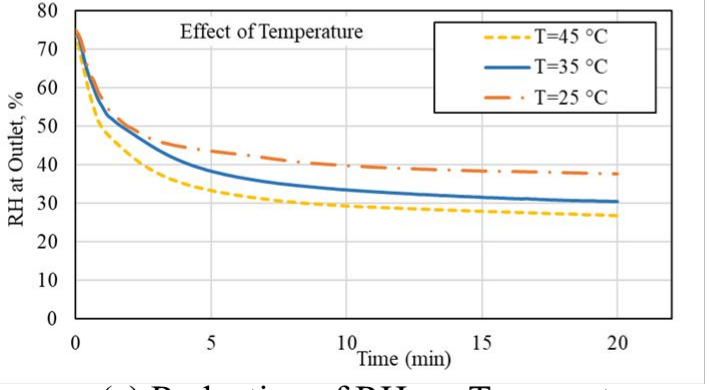
Lab-scale membrane system: Efficiency of water vapor removal from air



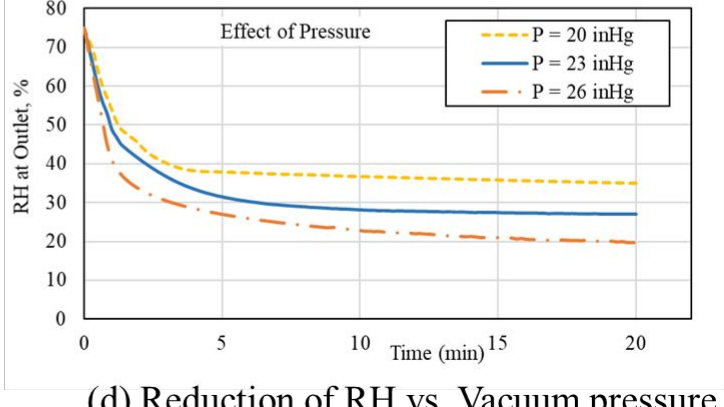
(a) Reduction of RH vs. airflow rate



(b) Reduction of RH vs. initial RH



(c) Reduction of RH vs. Temperature

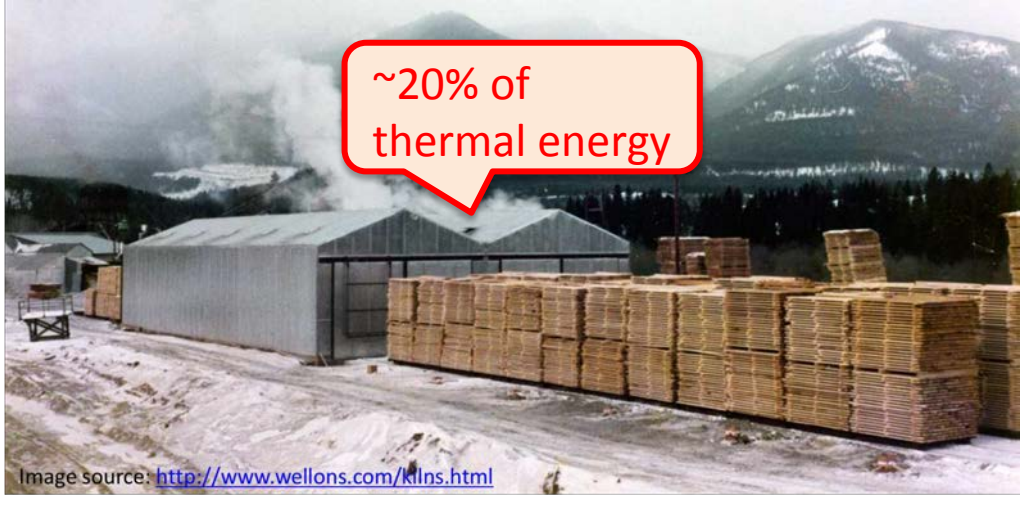


(d) Reduction of RH vs. Vacuum pressure

Introduction

Dense polymeric membrane for water vapor/air separation: Applications

https://www.mines.edu/coronavirus/hvac-faqs/

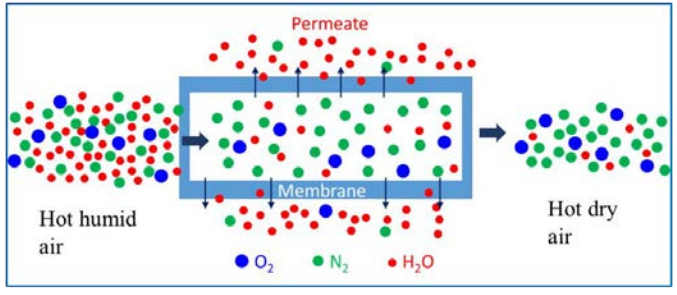


Pre-dehumidification of moist air before entering in HVAC: ~30% of cooling energy saving

Q: Dehumidification of moist exhaust air for thermal energy saving?

Introduction

Proposed Solution:



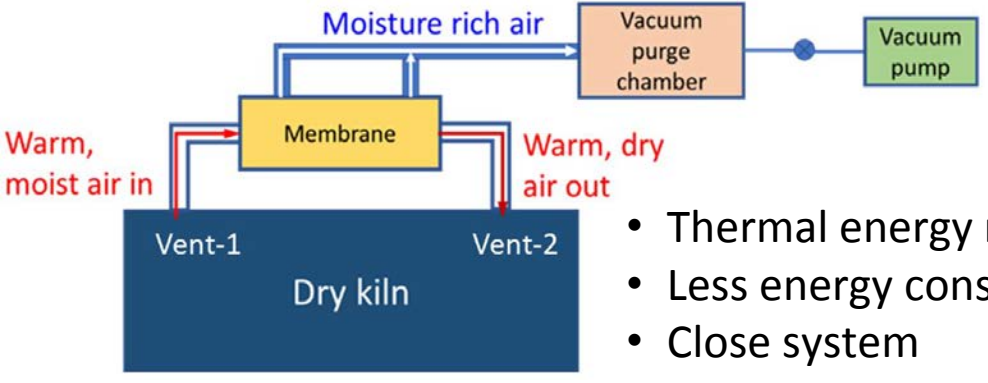
Hollow-fiber membrane

PDMS membrane:

- Operation temperature: <60°C
- Selectivity of H_2O/N_2 = 129

Goal and Objectives:

- Develop high performance composite membranes using nanocellulose as an additive



- Thermal energy recover
- Less energy consumption
- Close system

Introduction

Modification of hydrophilicity of dense membrane using nanocellulose

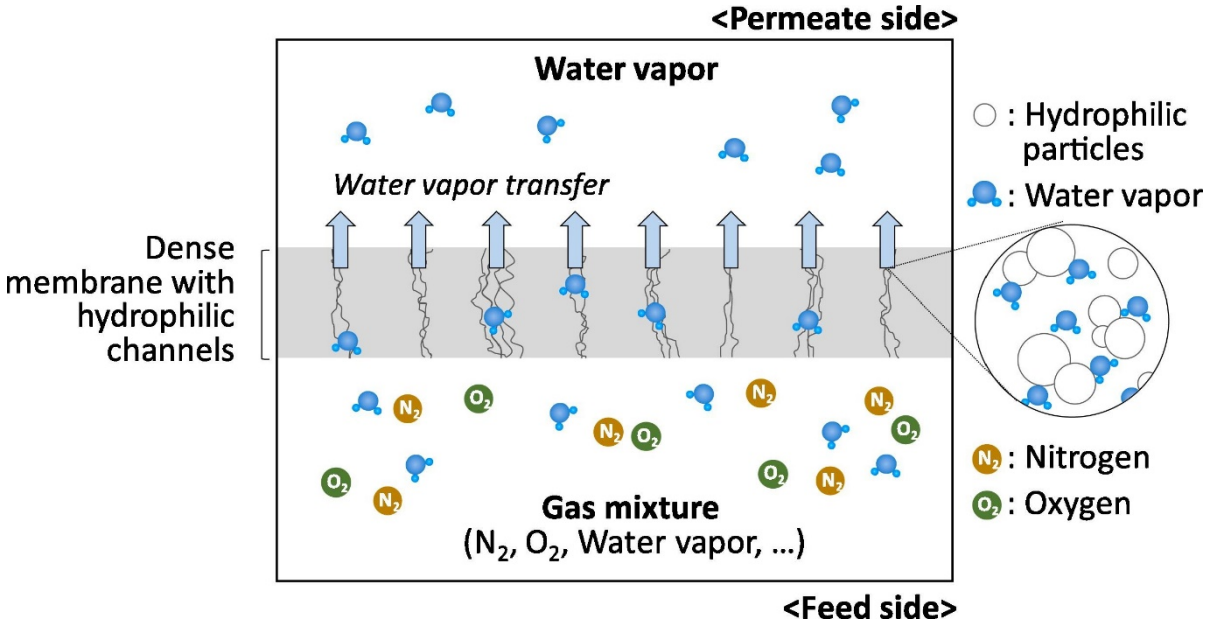
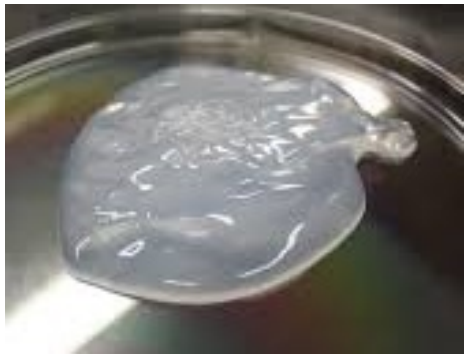
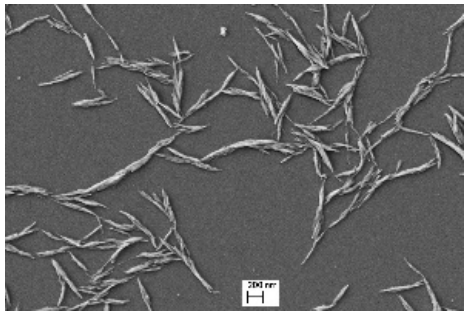


Image on the ideal separation of water vapor from gas mixture through hydrophilic channels of a dense membrane (Lim et al. 2020)

https://doi.org/10.1016/j.applthermaleng.2020.115676

Cellulose Nanocrystals (CNC)

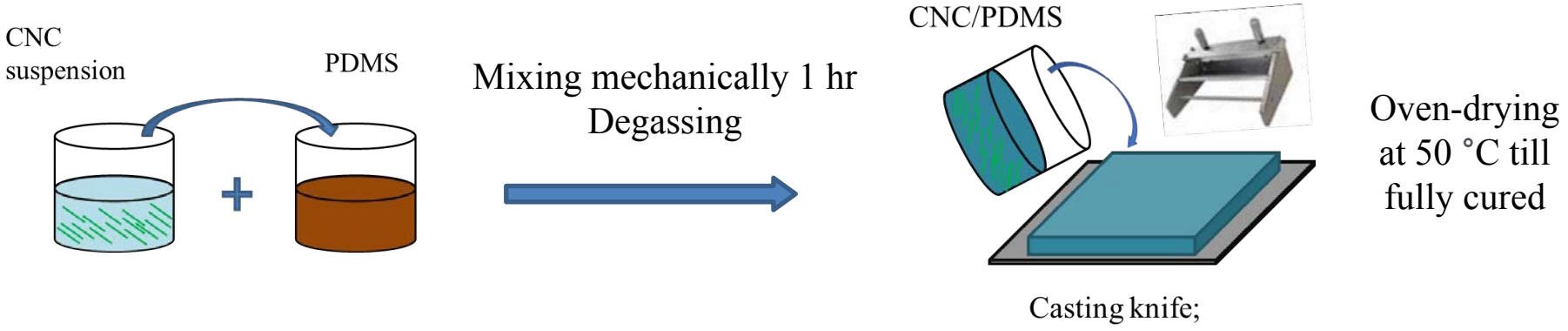




Development of CNC/PDMS Membrane

Experiment 1: Water-based CNC suspension

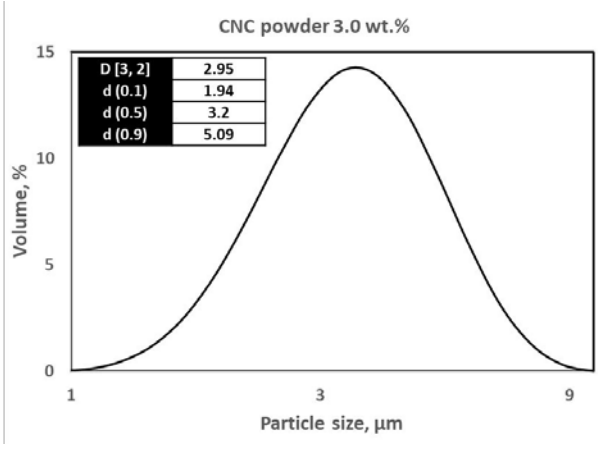
- CNC suspension at 11.8% solids
- PDMS prepolymer and curing agent kit (Dow SYLGARDTM 184 Silicone Elastomer kit, Dow Inc., MI, USA)
- CNC/PDMS composite membrane samples
  - CNC concentrations: 0% (Control), 2%

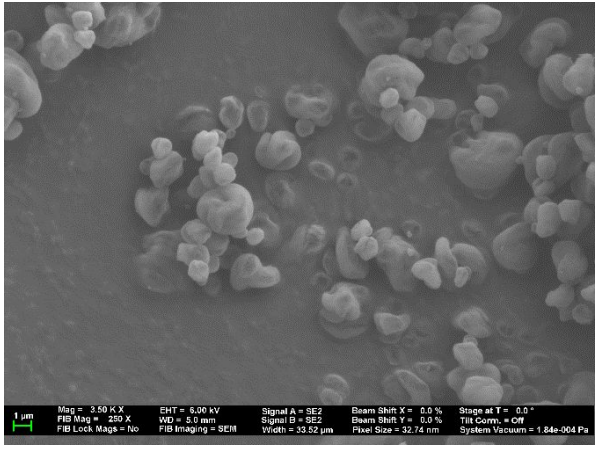


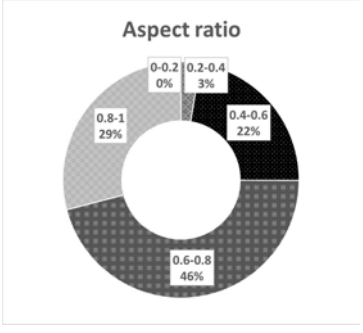
Development of CNC/PDMS Membrane

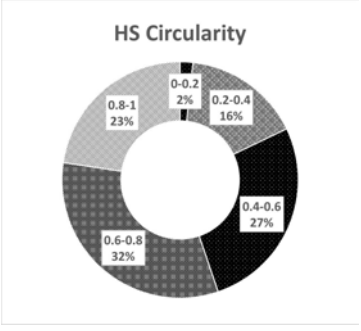
Experiment 2: Organic solvent-based CNC suspension

- Water-based CNC suspension at 3% solids used for making spray dry CNC powder
- BUCHI B-290 Mini Spray Dryer
  - Inlet Temperature – 175 °C
  - Outlet Temperature – 90-95 °C
  - Gas flow rate – 540 L/h
  - Feed rate – 8 mL/min
  - Aspirator – 100%







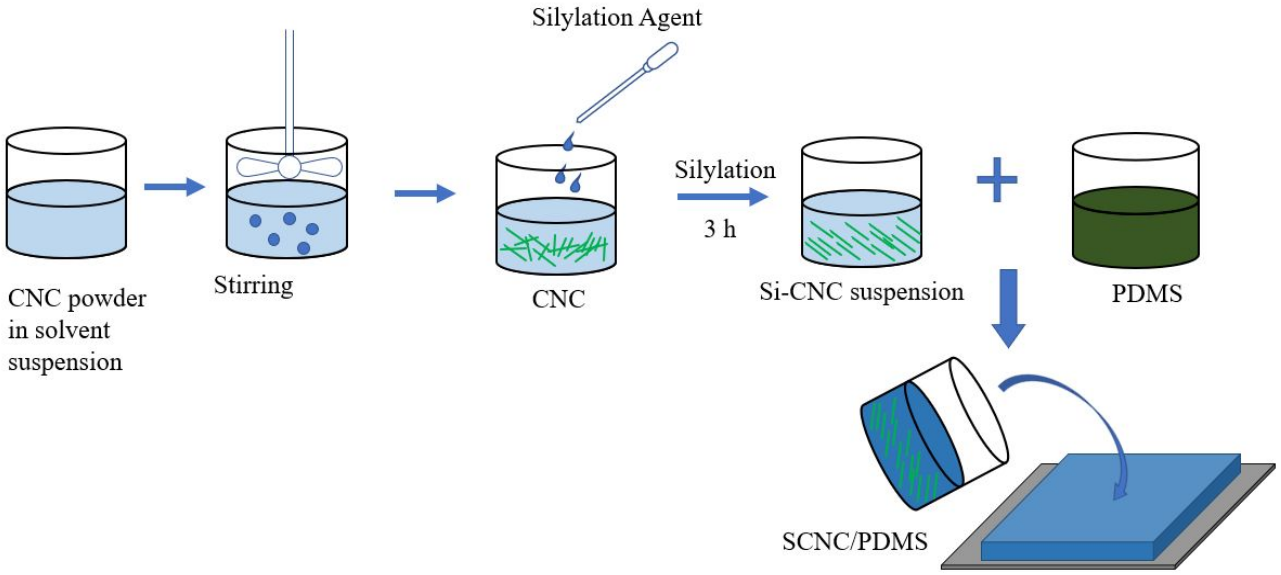


CNC spray drying done by Sungjun Hwang

ADVANCED STRUCTURES & composites center

Development of CNC/PDMS Membrane

Experiment 2: Organic solvent-based CNC suspension

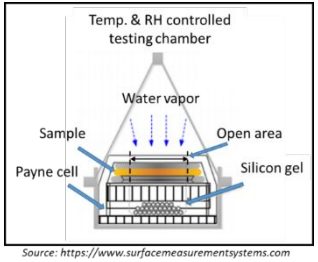


- Silylation of CNC to improve the compatibility of CNC and PDMS
- N-Hexane used as an organic solvent
- CNC concentration: 2%

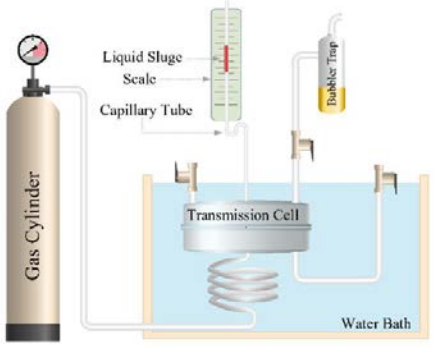
- n-Hexane (Thermo Fisher Scientific Chemicals, Massachusetts)
- Silylation agent: Trimethoxymethylsilane (MTMS) (sigma-Aldrich)
- Acetic acid, Fisher Scientific (New Jersey)

Development of CNC/PDMS Membrane

Permeability tests: Water vapor and Nitrogen



Dynamic Vapor Sorption



Gas permeability cell

- Temp: 25°C, 50°C, 80°C
- RH: 60%

$$P_{H_2O} = \frac{WVTR}{Diff. \cdot Vapor\ pressure}\left(\frac{mol}{m^2 \cdot h \cdot Pa}\right)$$

$$WVTR = \frac{1}{18 \times Area}\left(\frac{\Delta m}{\Delta t}\right)\left(\frac{mol}{m^2 \cdot h}\right)$$

$$Selectivity = \frac{P_{H_2O}}{P_{N_2}}$$

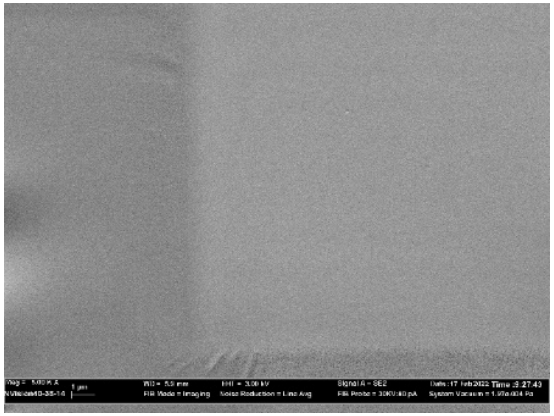
- Temp: 25°C, 50°C, 80°C

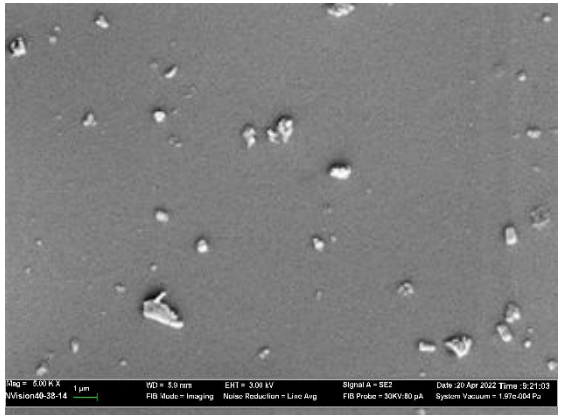
$$P_{N_2} = \frac{NTR}{Diff. \cdot Gas\ pressure}\left(\frac{mol}{m^2 \cdot h \cdot Pa}\right)$$

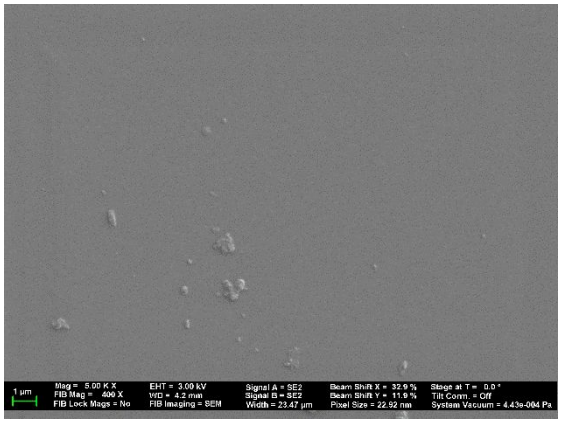
$$NTR = \frac{P}{RT \times Area}\left(\frac{\Delta V}{\Delta t}\right) \quad \left(unit: \frac{mol}{m^2 \cdot h}\right)$$

Development of CNC/PDMS Membrane

SEM and appearance of CNC/PDMS membrane samples







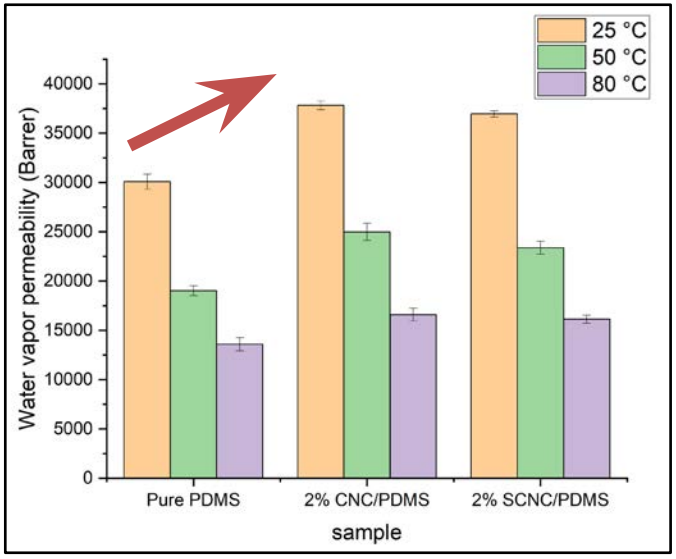
Pure PDMS

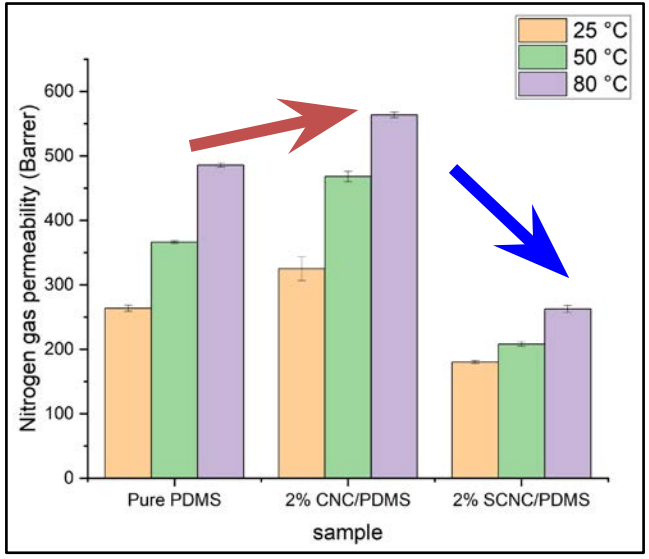
2% CNC/PDMS

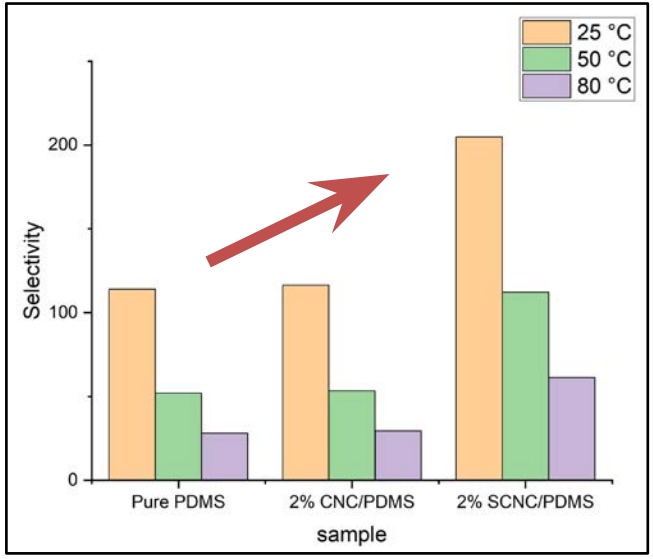
2% SCNC/PDMS

Development of CNC/PDMS Membrane

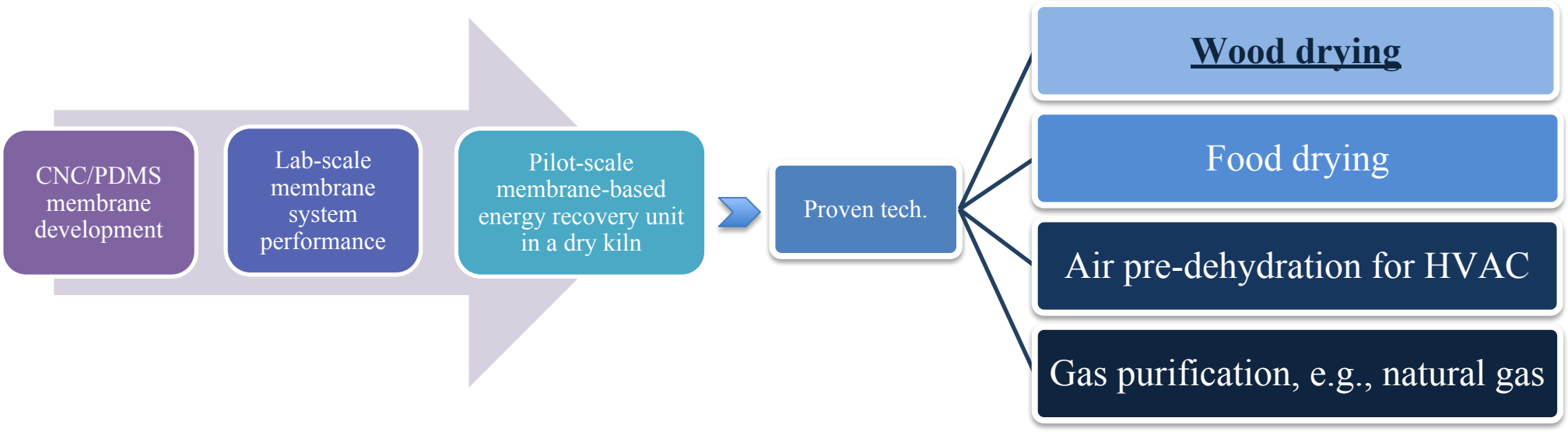
Results of water vapor and nitrogen gas permeability







Concluding Remarks



Scale-up & Commercialization Roadmap

Potential technology users

Next presentation (Dr. Rajendiran):

Techno-economic analysis and life cycle assessment of manufacturing a cellulose nanocrystal-based hybrid membrane

Microsoft Teams

NAVEENKUMAR RAJENDIRAN

2023-08-19 17:58 UTC

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Thank you & Questions?

Acknowledgements

USDA ARS

U.S. Endowment for Forestry and Communities

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