Dansk Mejeriteknisk Selskab

Billund, June 14th 2018

Challenges in the Dairy Industry:

Perspective on extreme performance membranes

OLE LILLEVANG, TECHNOLOGY SPECIALIST

GEA PRODUCT TECHNOLOGY CENTER FILTRATION

engineering for
a better world

Development in membranes and systems over time

engineering for a better world

- Design/
  - P&F
  - HF/tubular
  - Ceramic
  - Spiralwound

=> Better “area surface to volume” ratio vs. productivity

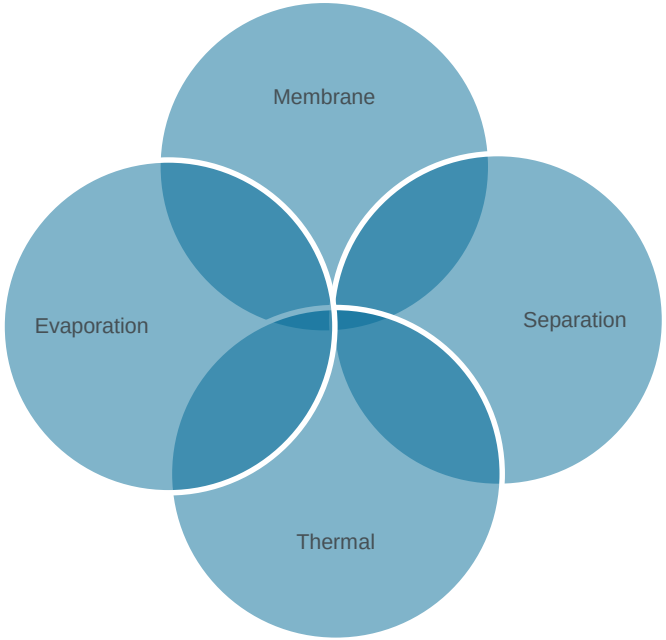
- Construction
  - Production:
    - Automation leading to uniform quality
  - Materials:
    - Mechanical stability
    - Durability (choice of membrane material, glue, backing etc.)

=> “Cheap”, reliable, massproduced membranes

Competing technologies

- Purposes:

- Separation
- Concentration
- Bacteria reduction

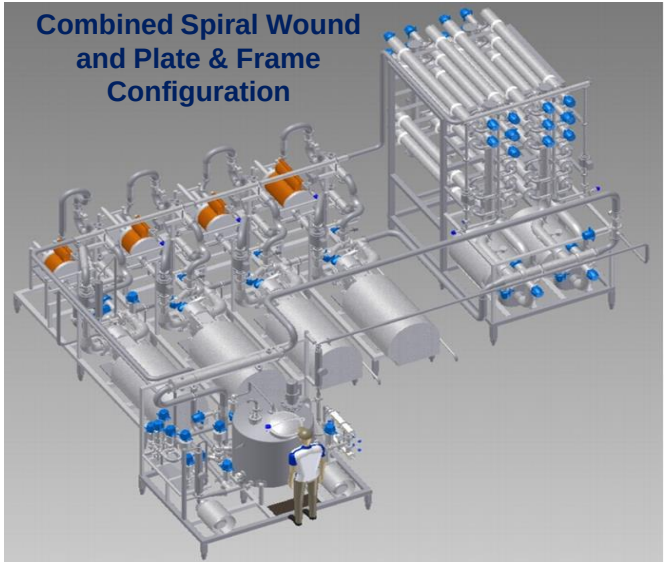


Why use membranes/substitute with membranes?

- Adding value
  - Eg. cheaper processing
- Solving issues
  - Eg. Thermophilic bacteria
- New products
  - Eg. Beverages (clarity, solubility)

Hybrid Spiral and Plate & Frame Systems

- Leads to very high concentrations of viscous products.
- Competes against separators and evaporators
- Application areas: High concentrations of fermented products such as cream cheese, Greek yogurt; MPCs.
- Disadvantage: cleaning, Production time, CAPEX/OPEX



CMF bacteria reduction Applications & benefit

Bacteria reduction in skim milk

- Extended Shelf Life (ESL) milk
  - Improved shelf life
  - No UHT taste (“fresh” milk like)
- Cheese milk improvement
  - Reducing/eliminating nitrate addition
  - Better cheese quality
  - Nitrate addition free whey
  - Improved shelf life (Mozzarella)
- Improved quality on powders, MPC’s, baby food etc.
  - Reduction of spores
  - Reduction of enzymes

Competes against bactofuges and UHT

Disadvantage: CAPEX/OPEX

Bacteria reduction in whey or WPC

- Improved whey powder quality
  - Reduction of spores
  - Reduction of enzymes

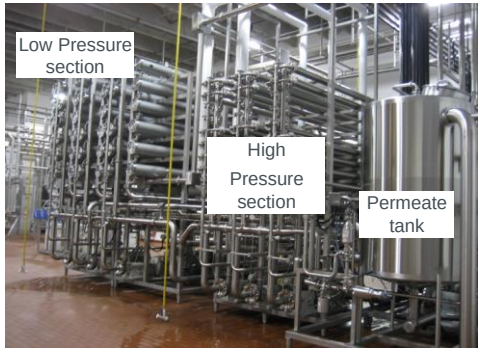
Challenges pushing further development of membranes: Do something we cannot do today!

- Why?
- Membranes are wear and tear parts with (relatively) poor lifetime
- Issues with biofilm/cleaning in generel
- Empirical modeling/secondary membrane
- Utility consumption (water, chemicals, energy)
- Life cycle: CO2 footprint/cradle to grave
  - Product (membrane)
  - Produced product
- Productivity
  - Fighting limits for processing
    - Viscosity, osmotic pressure
- Product quality
  - Sensitivity of product (eg. protein denaturation)
  - Texture
  - Purity

- Demands:
- Cheap!
- Easy to clean (clean with cold water only!)
- Sanitisable (thermal/mechanical?)
- Long shelflife
- High flux
- High mechanical integrity

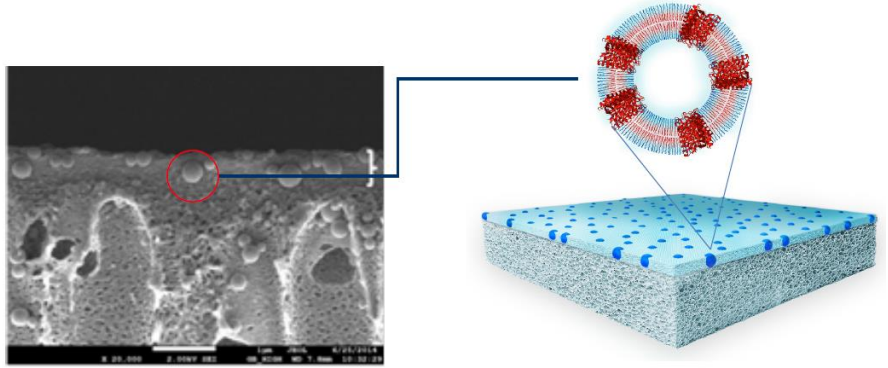
Ultra High Pressure RO and NF Technology

- Reverse Osmosis is a widely used technology for concentration of liquids.
- Most RO systems and membranes at present can only be operated at a maximum of 55 bar.
- This leads to limited concentration of solids for some products. Further concentration is achieved using thermal method such as evaporation or expensive method such as freeze concentration.
- UHPRO can operate at pressure > 55 bar to as high as 83 bar (or higher ?).
- With an UHPRO or UHPNF, very high concentrations of products can be achieved at low temperature. This will eliminate the need of any further concentration.
- UHPRO or UHPNF will result into superior product quality.
- Potential applications in dairy: Higher concentration of GOS, Skim Milk at very low temperatures.
  - < Thermal impact, < energy cost



Biomimetic Membranes

- These membranes are designed to mimic the highly selective transport of water and solutes across biological membranes.
- These membranes are made by incorporating biological membrane proteins (aquaporin) into the copolymer matrix.
- The resulting membrane is called Biomimetic membrane.
- These membranes were found to result in water permeability of about 100 times higher than commercial membranes (Kumar et al. 2007). These membranes also provide very high solute rejections.
-

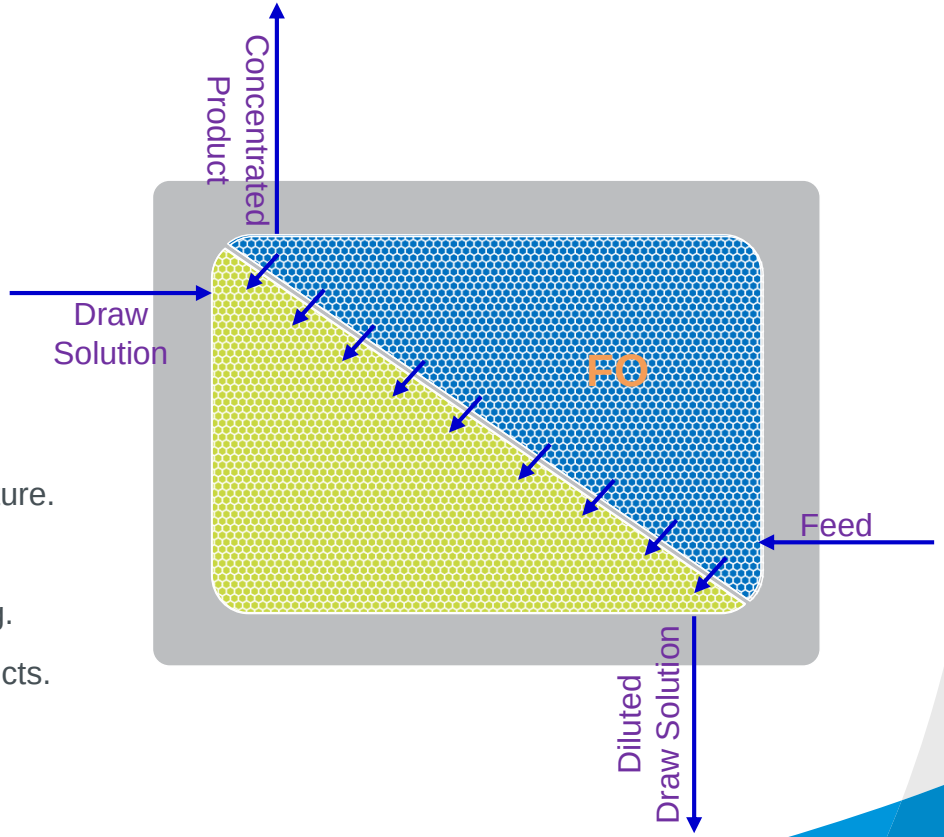


Picture courtesy of Aquaporin, DK

Introduction

Principle of Forward Osmosis

Water is drawn from a feed stream across a membrane by using draw solution of higher osmotic pressure. Difference in osmotic pressures between the draw and feed solutions is the driving force of FO.

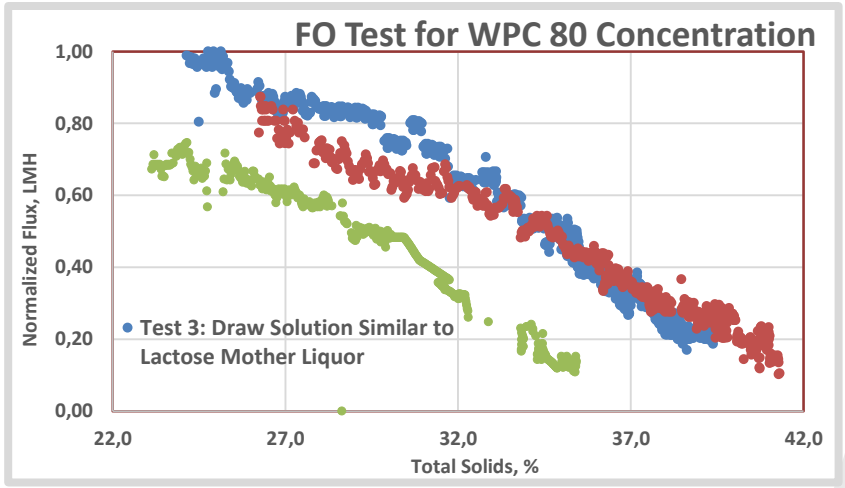


- Advantages:
- Concentrate products at low pressure and low temperature.
- Single feed pump
- Lower crossflow and economical CIP due to less fouling.
- Less hold-up volume, higher recovery of valuable products.
- Higher concentration of less viscous products

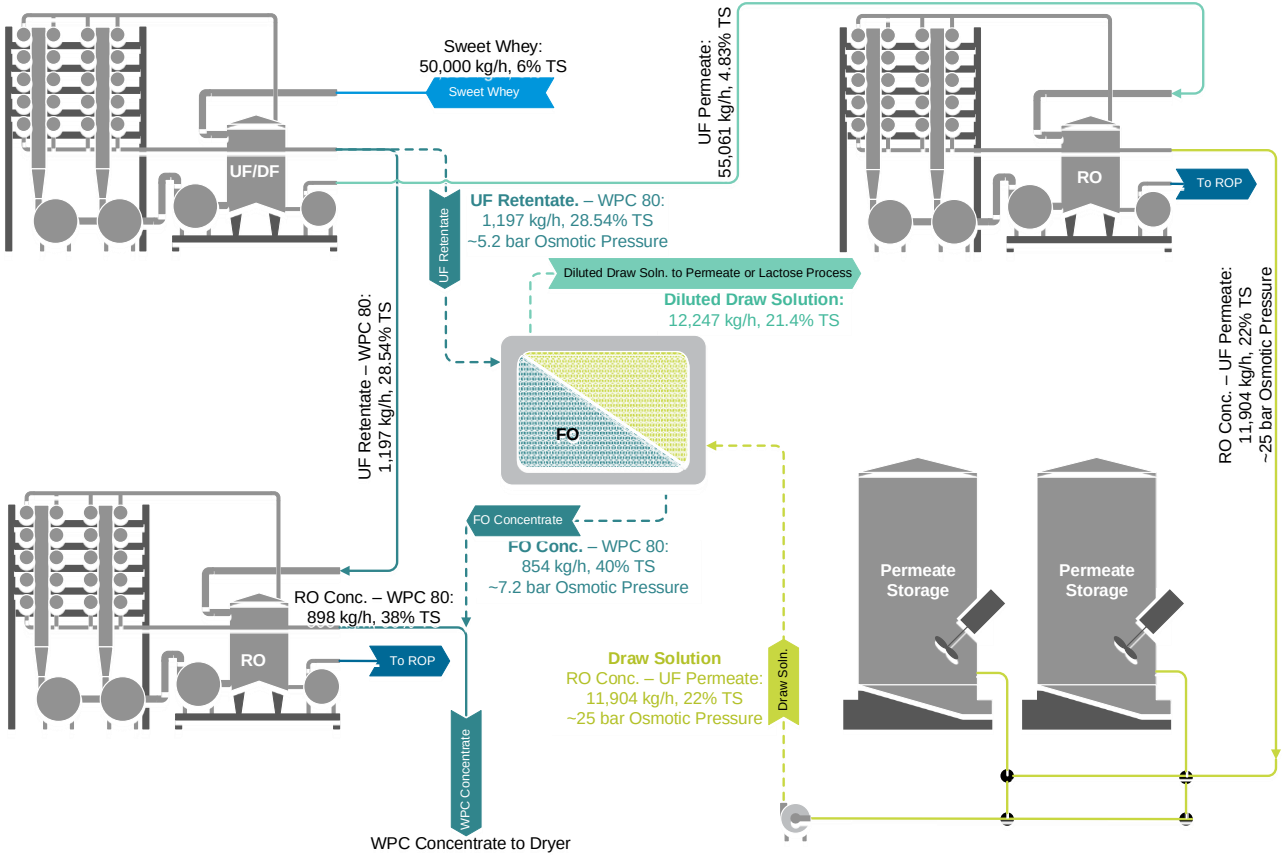
Forward Osmosis- Concentration of WPC80

- Utilizing a draw solution from amongst the less productive or effluent streams present inside the same factory as the feed product offers an economical regeneration path for the draw solution.
- FO studies were conducted to achieve over 40% total solids of 80% whey protein concentrate (WPC80) while using concentrated UF whey permeate, and lactose mother liquor as the draw solutions.

Solutions	Estimated Osmotic Pressure, bar
WPC UF Permeate Concentrated by 40 bar RO System- Draw Solution	25
WPC UF Permeate Concentrated by 60 bar RO System- Draw Solution	35
Mother Liquor generated during Lactose Processing- Draw Solution	> 65
WPC80 at 30% TS- Feed Solution for FO	5.4
WPC80 at 40% TS- Target FO Concentrate	7.2



Concentration of WPC80 by RO Concentrate – Industrial Scale



Charged Membranes

engineering for a better world

Membrane Filtration is a key process to isolate proteins

Works as a screen separating large from small components

Current technology based on separation only by size

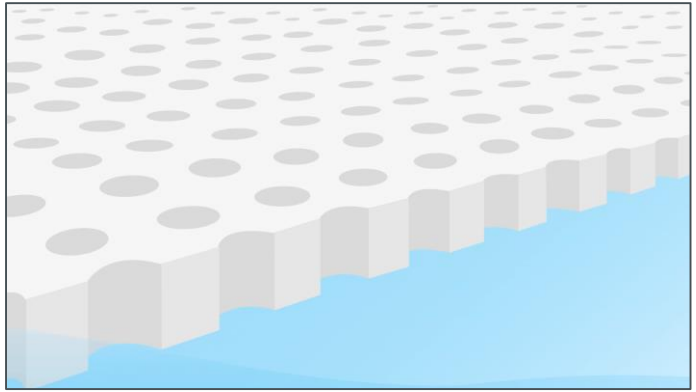
What is “Charged” Membrane?

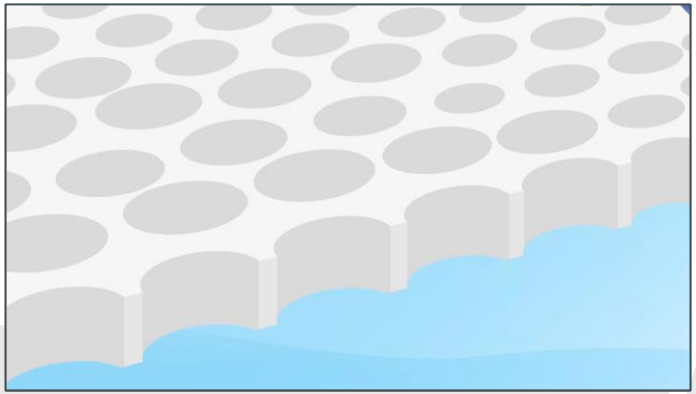
Apply electrical charge on membrane surface

Proteins are repelled by charge

Separation based on size and also electrical charge

Ability to separate similar sized components



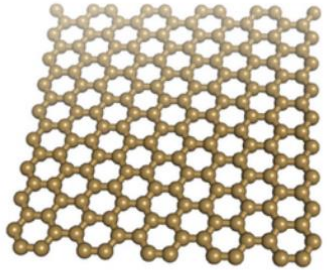


Advantages of Charged Membranes

- Higher production flux
- Low diafiltration water requirement
- Better selectivity of separation and fractionation (fractionation of different proteins)
- Higher concentration of products such as WPC’s, MPC’s, Skim Milk, Permeate, Lactose
- Longer running time
- Smaller plant size
- Low capital investment
- Less CIP chemical and water consumption
- Lower operating cost
- Replacement of technologies that is complex and less sustainable (e.g. ion-exchange, electrodialysis)

Graphene Oxide (GO) Membranes

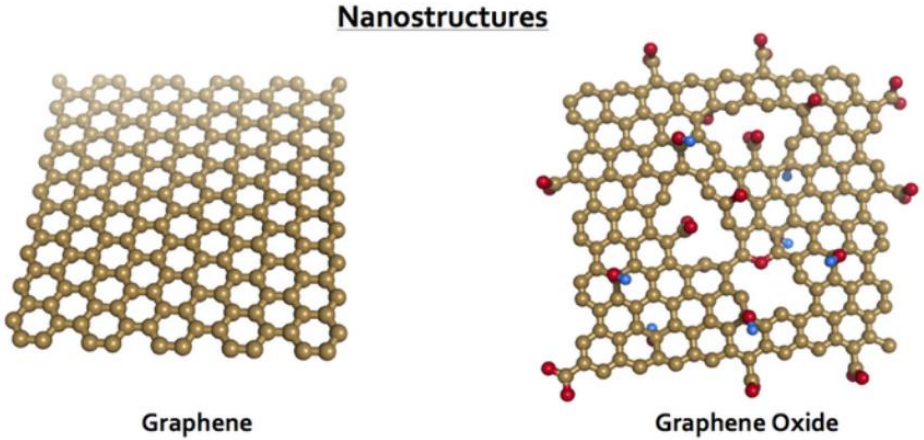
- Polymeric membranes are simple and easier to make, but suffer from poor chemical and thermal resistance, a limited lifetime and serious fouling issues.
- In contrast, ceramic inorganic membranes possess thermal and chemical including solvent stability, a very high lifetime. But, they are more complex (hard to make RO, NF and even tight UF) and expensive to fabricate and are also brittle.
- Graphite is inexpensive and available in abundance.
- Graphene is a single atomic oxide of Graphite in which monolayer of carbon atoms are packed in 2D honeycomb lattice nanostructure.
- The beneficial properties of graphene include high chemical and thermal strength, great flexibility and mechanical strength (not brittle), and inexpensive.
- Graphene sheets do not have pores.



Graphene

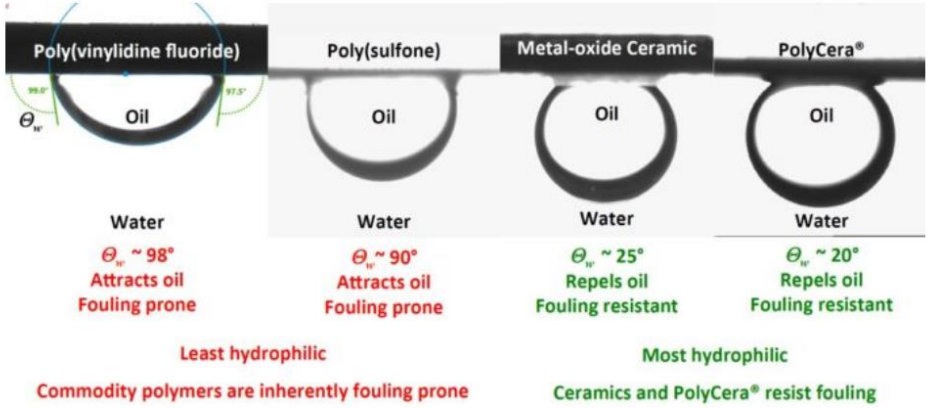
Graphene Oxide (GO) Membranes

- A Graphene oxide (GO) membrane is made by inserting pores in the graphene sheets.
- Pore size can be controlled leading to various membranes.
- GO membranes possess all the beneficial properties of the graphene material.
- GO membranes are also hydrophilic, thus severely reduce the membrane fouling.
- GO membranes can be functionalized to prevent biofouling.



PolyCera Membranes

- **Robust, easy to clean PolyCera membranes extend the range of ultrafiltration performance beyond conventional ceramic and polymeric membranes.**
- PolyCera® is a new polymeric material platform derived from Nobel Prize winning polymer chemistry developed into membrane materials at the University of California, Los Angeles (UCLA) and the California NanoSystems Institute (CNSI).
- PolyCera membranes offer a unique combination of extreme hydrophilicity, permeability and robustness. Improved hydrophilicity means improved fouling resistance and ease of cleaning, ultimately, less cost.
- PolyCera membranes are offered in our proprietary **Spiral Monolith®** module, which enables either dead-end (low-energy) or cross-flow (high-fouling) operation combined with hydraulic backwashing.



PolyCera Membranes

engineering for a better world

FEATURES

- Super hydrophilic material
- High sustainable flux
- Fouling resistant and easy to clean
- Extreme pH, temperature and oxidant stability
- High tolerance for oil, COD/BOD, NOM and other solvents
- Surface properties inhibit biofilm formation
- Cross-flow modules minimize accumulation of fouling materials
- Back-washing removes deposited fouling materials

BENEFITS

- 10x lower cost than commodity ceramics
- Low energy demand
- Less process downtime
- Maintains permeability longer (low irreversible fouling)
- Handles the most challenging waters
- Easy to clean
- Reduces energy consumption
- Saves chemicals
- Lowers operating costs

APPLICATIONS

- Industrial wastewater treatment, recycling and reuse
- Tertiary treatment of municipal wastewater for non-potable reuse
- Conventional air and high-purity oxygen membrane bioreactors
- Drinking water filtration and point-of-use water purification
- Pre-filtration for brackish and ocean water desalination

engineering for
a better world

Questions?