Membrane Filtration

Ranjan Sharma
Traditional vs membrane filtration

Traditional

Membrane
Membrane filtration

APV
Batch membrane filtration plant

1. Product tank
2. Feed pump
3. Circulation pump
4. Strainer
5. Membrane module
6. Cooler

Membrane filtration spectrum

![Diagram of membrane filtration spectrum](image)

*Fig. 6.4.1* Spectrum of application of membrane separation processes in the dairy industry.

Filtration spectrum

![Filtration Spectrum Diagram]

- **Reverse Osmosis**
  - Nano Filtration
    - Flavors & Fragrances
    - Antibiotics
    - Atomic Radii
    - Aqueous Salts
  - Ultra Filtration
    - Gelatin
    - Virus
    - Colloidal Silica
    - Plant Gums
    - Sugars
    - Lignosulphonate
    - Amino Acids
    - Proteins / Enzymes
    - Colorants
    - Oil Emulsions
    - Wood Resin

- **Micro Filtration**
  - Bacteria
  - Red Blood Cells
  - Blue Indigo Dye
  - Paint Pigment
  - Lanolin

- **Particle Filtration**
  - 1000,000
  - 125 - 15 PSI
  - 8.6 - 1 BAR

- **Mol. Wt.**
  - 100
  - 1,000
  - 100,000

- **Pressure**
  - 1000-400 PSI
  - 600 - 100 PSI
  - 200 - 70 PSI
  - 125 - 15 PSI

- **Microns**
  - 0.001
  - 0.01
  - 0.1
  - 1.0
  - 10.0

*GEA*
Membrane filtration - dairy

- **Reverse Osmosis (RO)**: 30-60
  - Membrane pore size: $10^{-3}$ to $10^{-2}$

- **Nano Filtration (NF)**: 20-40
  - Membrane pore size: $10^{-2}$ to $10^{-1}$

- **Ultra Filtration (UF)**: 1-10
  - Membrane pore size: $10^{-1}$ to $10^{0}$

- **Micro Filtration (MF)**: <1
  - Membrane pore size: $10^{0}$ to $10^{1}$

- **Feed**
- **Permeate (filtrate)**
- **Retentate (concentrate)**

- **Bacteria, fat**
- **Proteins**
- **Lactose**
- **Minerals (salts)**
- **Water**
Filtration processes - summary

- **MF**: Membrane Filtration (Microfiltration)
  - Removes Monovalent ions
  - Virus
  - Bacteria
  - Suspended solids

- **UF**: Ultrafiltration
  - Removes Monovalent ions
  - Virus
  - Bacteria
  - Suspended solids

- **NF**: Nanofiltration
  - Removes Monovalent ions
  - Virus
  - Bacteria
  - Suspended solids

- **RO**: Reverse Osmosis
  - Removes Monovalent ions
  - Virus
  - Bacteria
  - Suspended solids
Membrane filtration applications

- **Reverse osmosis (RO)**
  - Concentration of solution by removal of water

- **Nanofiltration (NF)**
  - Concentration of organic components by removal of part of monovalent ions like sodium and chlorine (partial demineralisation)

- **Ultrafiltration (UF)**
  - Concentration of large and macro molecules

- **Microfiltration (MF)**
  - Removal of bacteria, separation of macromolecules
## Comparison of membrane processes

<table>
<thead>
<tr>
<th>Table 2. Comparing Four Membrane Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membrane</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>Thickness Thin film</td>
</tr>
<tr>
<td>Pore size</td>
</tr>
<tr>
<td>Rejection of</td>
</tr>
<tr>
<td>Membrane material(s)</td>
</tr>
<tr>
<td>Membrane Module</td>
</tr>
<tr>
<td>Operating pressure</td>
</tr>
</tbody>
</table>
Applications of membrane filtration

<table>
<thead>
<tr>
<th>Type of Membrane Process</th>
<th>Permeate</th>
<th>Concentrate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RO</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dyeing effluent</td>
<td>clean water</td>
<td>BOD, salt, chemicals, waste products</td>
</tr>
<tr>
<td>water</td>
<td>low salinity water</td>
<td>salty water</td>
</tr>
<tr>
<td>whey</td>
<td>low BOD permeate</td>
<td>whey concentrate</td>
</tr>
<tr>
<td>antibiotics</td>
<td>salty waste product</td>
<td>desalted, concentrated antibiotics</td>
</tr>
<tr>
<td>dyeing effluent</td>
<td>clean, salty water</td>
<td>BOD/COD, color</td>
</tr>
<tr>
<td>water</td>
<td>softened water</td>
<td>waste product</td>
</tr>
<tr>
<td>whey</td>
<td>salty waste water</td>
<td>desalted whey concentrate</td>
</tr>
<tr>
<td><strong>NF</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>antibiotics</td>
<td>clarified fermentation broth</td>
<td>waste product</td>
</tr>
<tr>
<td>bio-gas waste</td>
<td>clarified liquid for discharge</td>
<td>microbes to be recycled</td>
</tr>
<tr>
<td>carrageenan</td>
<td>waste product</td>
<td>concentrated carrageenan</td>
</tr>
<tr>
<td>enzymes</td>
<td>waste product</td>
<td>high value product</td>
</tr>
<tr>
<td>milk</td>
<td>lactose solution</td>
<td>protein concentrate for cheese production</td>
</tr>
<tr>
<td>oil emulsion</td>
<td>oil free water (&lt;10 ppm)</td>
<td>highly concentrated oil emulsion</td>
</tr>
<tr>
<td>washing effluent</td>
<td>clarified water</td>
<td>dirty water (waste product)</td>
</tr>
<tr>
<td>water</td>
<td>clarified water</td>
<td>waste product</td>
</tr>
<tr>
<td>whey</td>
<td>lactose solution</td>
<td>whey protein concentrate</td>
</tr>
<tr>
<td>xanthan</td>
<td>waste product</td>
<td>concentrated xanthan</td>
</tr>
</tbody>
</table>
Membrane material

- Membranes may be composed of natural (e.g. modified natural cellulose polymers) or synthetic polymers (plastic materials) or inorganic ceramic materials
  - be good film formers,
  - manage high permeate flows,
  - have high selectivity,
  - have good chemical and bacteriological resistance,
  - be resistant to detergents and disinfectants,
  - be inexpensive.
Membrane material – cellulose acetate

• Mostly for RO and UF
• Advantages
  • easy to manufacture, provide high flux and have high salt rejection properties
• Disadvantages
  • limited temperature range (max 30°C),
  • limited pH range (pH 3-6) – problem for cleaning with detergents
  • poor resistance to chlorine as a sanitiser,
  • poor membrane properties at high operating pressures
  • susceptibility to microbial attack due to their natural origin
Membrane material – synthetic polymers

- Polyamide and polysulphone
- Widely used for UF
- Wide tolerance to pH, temperature and chlorine
Membrane material – ceramic

- Made from mineral materials such as glass, aluminium oxide and zirconium oxide
- High resistance to chemical degradation, and tolerate wide pH and temperature ranges
- Expensive and can be brittle
- Mainly used for microfiltration
Chemical resistance of membrane material

<table>
<thead>
<tr>
<th></th>
<th>Composite</th>
<th>CA</th>
<th>PSO</th>
<th>PVDF</th>
<th>PAN</th>
<th>SiO₂</th>
<th>Cellulose</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH&lt;3 or pH&gt;8</td>
<td>✓</td>
<td>✓</td>
<td>✔</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Temp &gt;35°C</td>
<td>✓</td>
<td>✔</td>
<td>✔</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Humic acid</td>
<td>(✓)</td>
<td>✔</td>
<td>✗</td>
<td>✗</td>
<td>(✓)</td>
<td>✗</td>
<td>✔</td>
</tr>
<tr>
<td>Proteins</td>
<td>✓</td>
<td>✔</td>
<td>✔</td>
<td>(✓)</td>
<td>(✓)</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Polysaccharides</td>
<td>(✓)</td>
<td>✗</td>
<td>✔</td>
<td>✗</td>
<td>(✓)</td>
<td>✔</td>
<td>✗</td>
</tr>
<tr>
<td>Textile waste</td>
<td>✓</td>
<td>✗</td>
<td>✔</td>
<td>(✓)</td>
<td>✓</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Aliphatic hydrocarbon</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>(✓)</td>
<td>✓</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Aromatic hydrocarbon</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
<td>✗</td>
<td>✔</td>
<td>(✓)</td>
</tr>
<tr>
<td>Oxidizers</td>
<td>✗</td>
<td>(✓)</td>
<td>✔</td>
<td>(✓)</td>
<td>✔</td>
<td>(✓)</td>
<td></td>
</tr>
<tr>
<td>Ketones, Esters</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
<td>✗</td>
<td>✔</td>
<td>(✓)</td>
</tr>
<tr>
<td>Alcohol</td>
<td>✓</td>
<td>✗</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

Wagner, 2001, Membrane Filtration Handbook
## Membrane manufacturers

**Table 6. An Incomplete List of the Major Players as of 2001**


<table>
<thead>
<tr>
<th>Owned By</th>
<th>Company Size</th>
<th>Tubular Membrane</th>
<th>Spiral Wound Element</th>
<th>Fiber System</th>
<th>Ceramic Membrane</th>
<th>RO</th>
<th>NF</th>
<th>UF</th>
<th>MF</th>
<th>Process</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTI</td>
<td>Small</td>
<td>☑</td>
<td>☑</td>
<td></td>
<td>USA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSS</td>
<td>Small</td>
<td>☑</td>
<td></td>
<td></td>
<td>DK</td>
<td>☑</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FilmTec</td>
<td>Dow Chemicals</td>
<td>Big</td>
<td>☑</td>
<td></td>
<td>USA</td>
<td>☑</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluid Systems</td>
<td>Koch</td>
<td>Medium</td>
<td>☑</td>
<td></td>
<td>USA</td>
<td>☑</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hoechst</td>
<td>KC5</td>
<td>Small</td>
<td>☑</td>
<td></td>
<td>Germany</td>
<td>☑</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydranautics</td>
<td>Toray</td>
<td>Medium</td>
<td>☑</td>
<td></td>
<td>USA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kiryat Weizman</td>
<td>Koch</td>
<td>Small</td>
<td>✓</td>
<td>✓</td>
<td>Israel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Koch/Abcor</td>
<td>Medium</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>USA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osmonics</td>
<td>Medium</td>
<td>✓</td>
<td></td>
<td></td>
<td>USA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCI</td>
<td>Thames Water</td>
<td>Small</td>
<td>✓</td>
<td></td>
<td>England</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rochem</td>
<td>Pall</td>
<td>Small</td>
<td></td>
<td></td>
<td>Germany</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCT</td>
<td>Small</td>
<td></td>
<td>✓</td>
<td></td>
<td>France</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stork Friesland</td>
<td>Small</td>
<td>✓</td>
<td></td>
<td></td>
<td>Holland</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Synder</td>
<td>Small</td>
<td></td>
<td></td>
<td></td>
<td>USA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tami</td>
<td>Small</td>
<td></td>
<td>✓</td>
<td></td>
<td>France</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toray</td>
<td>Medium</td>
<td></td>
<td>✓</td>
<td></td>
<td>Japan</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trisep</td>
<td>Medium</td>
<td></td>
<td>✓</td>
<td></td>
<td>USA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>XFLOW</td>
<td>Small</td>
<td></td>
<td>✓</td>
<td></td>
<td>Holland</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Wagner, 2001, Membrane Filtration Handbook
Membrane modules

- Plate and frame
- Spiral wound
- Tubular, based on polymers
- Tubular, based on ceramics
- Hollow-fibre
Plate and frame design

- Membrane sandwiched between membrane support plates which are arranged in stacks similar to a plate heat exchanger
- Typically polymers (e.g. polyethersulfone) with polypropylene or polyolefin support
- UF (<1 to 1000 kDa MWCO)
- MF (0.1 to 0.16 um diameter)
Plate and frame membrane systems

- Oval shaped
- Rectangle shaped

Retentate
Permeate
Feed

Oval shaped
Rectangle shaped
Plate and Frame module

Nirosoft waste water system

http://www.nirosoft.com/site/item.php?ln=en&item_id=189&main_id=110
Plate and Frame module

Nirosoft waste water system

http://www.nirosoft.com/site/item.php?ln=en&item_id=189&main_id=110
Spiral Wound membrane

Wagner, 2001, Membrane Filtration Handbook
Spiral Wound membrane – cross-section
Hollow fibre membrane

- Hollow-fibre
  - a narrow tube made of a non-cellulosic polymer
Hollow fibre membrane
Hollow fibre membrane
Tubular design - polymers

- Stainless steel tubes in shell and tube construction
- Membrane insert
- PCI – Patterson and Candy International
Tubular design - ceramic

- Channels
  - fine-grained ceramic
- Support
  - Coarse-grained ceramic
- Applications
  - removal of bacteria from milk, whey, WPC, brine
- French company - SCT

Dairy Processing Handbook
## Comparison of membrane modules

<table>
<thead>
<tr>
<th>System</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat Sheet/Plate and</td>
<td>1. Low hold up volume</td>
<td>1. Difficult to clean</td>
</tr>
<tr>
<td>Frame</td>
<td>2. Permeate from individual membrane element</td>
<td>2. Susceptible to plugging</td>
</tr>
<tr>
<td></td>
<td>3. Membrane replacement easy</td>
<td></td>
</tr>
<tr>
<td>Spiral</td>
<td>1. Compact</td>
<td>1. Not suitable for very viscous fluidWound</td>
</tr>
<tr>
<td></td>
<td>2. Minimum energy consumption</td>
<td>2. Dead spaces</td>
</tr>
<tr>
<td></td>
<td>3. Low capital/operating cost</td>
<td>3. Difficult to clean</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Faulty membrane - change whole module</td>
</tr>
<tr>
<td>Hollow Fibre</td>
<td>1. Low hold up volume</td>
<td>1. Susceptible to end-face fouling</td>
</tr>
<tr>
<td></td>
<td>2. Backflushing possible</td>
<td>2. Not suitable for viscous fluids</td>
</tr>
<tr>
<td></td>
<td>3. Low energy consumption</td>
<td>3. Single fibre damage - replace entire module</td>
</tr>
<tr>
<td>Tubular</td>
<td>1. Feed stream with particulate matter can be put through membrane</td>
<td>1. High energy consumption</td>
</tr>
<tr>
<td></td>
<td>2. Easy to clean</td>
<td>2. High hold-up volume</td>
</tr>
</tbody>
</table>

30
Comparison of membrane modules

<table>
<thead>
<tr>
<th>Table 11. Comparison Between Several Membrane Modules</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spiral wound element</strong></td>
</tr>
<tr>
<td>Membrane density [m2/m3]</td>
</tr>
<tr>
<td>Plant investment</td>
</tr>
<tr>
<td>Tendency to fouling</td>
</tr>
<tr>
<td>Cleanability</td>
</tr>
<tr>
<td>Variable costs</td>
</tr>
<tr>
<td>Change of membrane only, see note 1</td>
</tr>
<tr>
<td>Flow demand</td>
</tr>
<tr>
<td>Prefilter other demands (see also table 26)</td>
</tr>
</tbody>
</table>

Wagner, 2001, Membrane Filtration Handbook
## Filtration modules

<table>
<thead>
<tr>
<th></th>
<th>RO</th>
<th>NF</th>
<th>UF</th>
<th>MF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spiral-wound</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Plate and frame</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Tubular (polymers)</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Tubular (ceramics)</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Hollow-fibre</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Membrane structure

• Asymmetric
  • Same material throughout, but has a thin, tight skin on the surface of the feed side so that the skin is the effective filtration layer, and the more open and thicker sub layer serves as a support for the skin
  • Most widely used for both UF and RO
• Symmetrical
  • Same material with the same structure throughout
• Composite asymmetric membranes
  • A thin polymer membrane on a microporous sub layer of another material
Batch operation

Energy inefficient
Continuous operation with single pass

Not practical
Too large area requirement
Continuous operation feed and bleed

Feed

Feed tank

Retentate

Permeate

Concentrate or Retentate

Recycle loop
Multistage operation
Factors affecting membrane performance - fouling

- **Concentration polarisation**
  - Differential solute conc between membrane surface and bulk stream
  - Reversibly affected by operation parameters

- **Fouling**
  - Formation of deposits
  - Irreversibly affected by operation parameters
Concentration polarisation
Membrane fouling

- **Two types**
  - Surface (temporary) fouling
  - Pore (permanent) fouling
Membrane fouling

- **Surface (temporary) fouling**
  - Foulant appears as an evenly deposited layer on the membrane surface
  - Can be easily removed by cleaning solution
  - Permeation rate of membrane can be regenerated by cleaning
  - Most common type of fouling in UF plant
  - Most studies dealt with this type of fouling
Membrane fouling

• Pore (permanent) fouling
  • Particulate matter diffuses into the membrane
  • Could be caused by the poor quality of the cleaning water
  • Uneven distribution of the foulant and compression of the separation zone
  • Flux cannot be regenerated by cleaning
  • Determines the lifetime of the membrane
  • Received much less attention in literature
Membrane fouling

• Implications
  • More energy consumption
  • Duration of continuous operation without need for cleaning
  • Membrane durability
  • Properties and quality of concentrate
  • Overall economy of the membrane process
Ultrafiltration

- Can be defined as a pressure-driven membrane process that can be used in separation and concentration of substances having a molecular weight between $10^3 - 10^6$ Daltons
- Most widely used in dairy industry
Applications of UF in dairy industry

- Protein standardisation
- Milk solids fortification for yogurt
- Cheese
  - Increased yield
- Whey protein concentrate and isolate (WPC/WPI)
  - Protein concentration
- Milk protein concentrate and Isolate (MPC/MPI)
  - Protein concentration
Five fold concentration of milk by UF

<table>
<thead>
<tr>
<th>Milk Component</th>
<th>Feed 100 L Milk</th>
<th>Concentrate 20L</th>
<th>Permeate 80L</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Fat</td>
<td>4.0</td>
<td>20.0</td>
<td>0.0</td>
</tr>
<tr>
<td>% Protein</td>
<td>3.5</td>
<td>17.5</td>
<td>0.0</td>
</tr>
<tr>
<td>% Lactose</td>
<td>4.8</td>
<td>4.8</td>
<td>4.8</td>
</tr>
<tr>
<td>% Salts</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>% Total Solids</td>
<td>13.0</td>
<td>43.0</td>
<td>5.5</td>
</tr>
<tr>
<td>% Water</td>
<td>87.0</td>
<td>57.0</td>
<td>94.5</td>
</tr>
</tbody>
</table>
UF – Commercial UF plant set up
WPC

• UF spiral-wound membrane
  • MW cutoff: 10000 Da
  • DF required for higher than 60% protein
• Whey protein concentrate
• 35-85% protein in dry matter
  • UF : 25-30% solids
  • MF to remove fat
  • DF to remove more lactose and minerals
  • Spray drying
• WPI (>90% protein)
  • UF/DF
  • Microfiltration to remove fat
### WPC – Whey composition

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total solids</td>
<td>6.0-6.5%</td>
</tr>
<tr>
<td>Lactose</td>
<td>4.5-5.0%</td>
</tr>
<tr>
<td>Minerals</td>
<td>0.5-0.7%</td>
</tr>
<tr>
<td>Proteins</td>
<td>0.8-1.0%</td>
</tr>
<tr>
<td>α-lactalbumin</td>
<td></td>
</tr>
<tr>
<td>β-lactoglobulin</td>
<td></td>
</tr>
<tr>
<td>BSA</td>
<td></td>
</tr>
<tr>
<td>Ig</td>
<td></td>
</tr>
<tr>
<td>Lactoferrin</td>
<td></td>
</tr>
</tbody>
</table>

**Sweet whey**
- pH: 6.2-6.4

**Acid whey**
- pH: 4.6-5.0
WPC

- To increase flux
  - Demineralisation Calcium removal (electrodialysis)
  - Sequestering agent (SHMP)
  - Increase pH to 7.5 (calcium phosphate precipitate)
  - Preheating 60°C for 30 min; UF at 50°C
  - Microfiltration
## Effect of diafiltration on composition

<table>
<thead>
<tr>
<th>Milk Component</th>
<th>Retentate/Concentrate 20L</th>
<th>Diluted 50:50 with water 40L total</th>
<th>Retentate/Concentrate 20L</th>
<th>Permeate 20L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat %</td>
<td>20.0</td>
<td>10.0</td>
<td>20.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Protein %</td>
<td>17.5</td>
<td>8.75</td>
<td>17.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Lactose %</td>
<td>4.8</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>Salts %</td>
<td>0.7</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Total Solids %</td>
<td>43.0</td>
<td>21.5</td>
<td>40.25</td>
<td>2.75</td>
</tr>
<tr>
<td>Water %</td>
<td>57.0</td>
<td>78.5</td>
<td>58.75</td>
<td>97.25</td>
</tr>
</tbody>
</table>
Modern WPC plant

Feed flow – 100,000 L/h constant feed rate
Temperature - cold
Milk protein concentrate

- Concentrating both casein and whey proteins
- Ratio similar to milk
- Applications:
  - Cheese milk extension
  - Nutritional beverages
## MPC Composition

<table>
<thead>
<tr>
<th>Components (% wt/wt)</th>
<th>NFDM</th>
<th>MPC-56</th>
<th>MPC 75</th>
<th>MPC 80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein</td>
<td>35</td>
<td>56</td>
<td>75.0</td>
<td>80.0</td>
</tr>
<tr>
<td>Water</td>
<td>4.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Fat</td>
<td>1.0</td>
<td>1.2</td>
<td>1.5</td>
<td>1.7</td>
</tr>
<tr>
<td>Lactose</td>
<td>51.3</td>
<td>31</td>
<td>10.9</td>
<td>5.5</td>
</tr>
<tr>
<td>Minerals</td>
<td>7.7</td>
<td>8.0</td>
<td>8.2</td>
<td>7.4</td>
</tr>
</tbody>
</table>
MPC Manufacturing Process

1. Raw Milk
2. Pasteurization
3. Separation
   - Cream
   - Skim milk
4. Ultra/diafiltration
   - Water
   - Permeate
   - UF Concentrate
5. Pasteurization/UHT
   - Evaporation
     - Water
   - UF/EV concentrate
6. Spray Drying
   - Water
7. MPC
   - Water
UF in cheese making

- Protein standardisation 3.6-4.0%
  - Consistent cheese quality
- Pre-concentration – 2X
  - Increased throughput
- Partial concentration 20% and 40% TS
  - Open structure cheese
  - Modified equipment needed
- Total concentration
  - Suitable for closed structure cheese
  - Modified equipment needed
Applications of UF in dairy industry

1 Milk tank
2 Pre-treatment, incl. thermisation
3 Ultrafiltration module
4 After-treatment of retentate incl. pasteurisation
5 Mixing tank
6 Dosing pump
7 Static mixers
8 Curd making machine
9 Curd cutting unit
10 Mould filling
11 Whey drainage and turning
12 Mould emptying
13 Brining
14 Ripening store

Dairy Processing Handbook

60
Reverse osmosis

- **Osmosis**
- Pure water flows from a dilute solution through a semipermeable membrane (water permeation only) to a higher concentrated solution
- Rise in volume to equilibrate the pressure (osmotic pressure)

http://www.trionetics.com/an001.pdf
Reverse osmosis

- Reverse osmosis
- If pressure greater than the osmotic pressure is applied to the high concentration the direction of water flow through the membrane can be reversed.

http://www.trionetics.com/an001.pdf
Reverse osmosis

http://www.trionetics.com/an001.pdf
Reverse osmosis

- 3-10 MPa
- Remove water against osmotic pressure
- \( \Pi = 0.7 \) MPa
- Water and small molecules diffuse through
- 30% dry matter achievable
- Gel layer formed by casein
- Whey proteins at pH < 6
- Calcium phosphate a problem at pH 6.6
Reverse osmosis

- **Milk - Can be used for concentration up to 30% TS**
  - Fat globules increases viscosity
  - Homogenization in retentate through the pressure release valve
  - Lactose crystallization
  - Applied to permeate from UF or whey
Whey powder - RO

- Separation of fat and casein fines
- Pasteurization
- Concentration
  - Reverse osmosis
  - Vacuum evaporation (45-65%)
  - (Lactose crystallization)
- Spray drying
Nanofiltration (NF)

- New class of pressure-driven membrane processes that lies between UF and RO
- Pressure range - 10-50 bar
- Rejects ions with more than one negative charge (such as $\text{SO}_4^{2-}$, $\text{CO}_3^{2-}$)
Nanofiltration

- Removal of inorganic salts
  - Na, K, Cl, urea, lactic acid,
- Partial demineralization
- Membranes that leak particle species with a radius in the nanometer range
- Reduce salty taste
- Pretreatment for electrodialysis, ion exchange
- Acid removal
- Reduce salt from cheese making
Lab NF equipment – DDS Lab 20 Plate & Frame

NF - Salt rejection by different NF membranes

- 0.2M NaCl
Δ - 0.2M Na sulphate

NF – rejection at 30 bar at 25C

MW 200-1500 Da - >90% rejected

### NF - Commercial NF membranes

<table>
<thead>
<tr>
<th>Name</th>
<th>DK</th>
<th>GE (G5)</th>
<th>GH (G10)</th>
<th>NP030</th>
<th>NP010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>GE W&amp;P Technologies</td>
<td>Microdyn-Nadir</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internet</td>
<td><a href="http://www.geawater.com">http://www.geawater.com</a></td>
<td><a href="http://www.microdyn-nadir.com">http://www.microdyn-nadir.com</a></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material of separation layer</td>
<td>TFC</td>
<td>TFC</td>
<td>TFC</td>
<td>Permanently hydrophilic polyethersulfone</td>
<td>Permanently hydrophilic polyethersulfone</td>
</tr>
<tr>
<td>MWCO</td>
<td>150-300</td>
<td>1000</td>
<td>2500</td>
<td>~150-300</td>
<td>~1000</td>
</tr>
<tr>
<td>Pure water flux (kg/h/m²/bar)</td>
<td>5.5 +/- 25%</td>
<td>1.2 +/- 25%</td>
<td>3.2 +/- 25%</td>
<td>&gt;1</td>
<td>&gt;5</td>
</tr>
<tr>
<td>Classification</td>
<td>NF</td>
<td>UF</td>
<td>UF</td>
<td>NF</td>
<td>NF</td>
</tr>
</tbody>
</table>

MF - Microfiltration

- Two filter modules connected in series
- One retentate circulation pump
- One permeate circulation pump
MF – industrial two module MF system

- Two filter modules connected in series
- One retentate circulation pump
- One permeate circulation pump
MF – Design principle of MF filter loop

1. MF membrane cartridge
2. Circulation pump for permeate
3. Circulation pump for retentate
MF - Hollow fibre design

A – filtration
B – Back flushing
C - Cleaning
MF - buttermilk

MF (0.8 um)
▲ 50°C; ■ 25°C; ◆ 7°C

J Dairy Sci 2004, 87, 267
### MF - buttermilk

<table>
<thead>
<tr>
<th></th>
<th>Fresh buttermilk</th>
<th>MF permeates 0.8 μm</th>
<th>MF retentates 0.8 μm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>7°C</td>
<td>25°C</td>
</tr>
<tr>
<td>Protein (% DM)</td>
<td>30.33</td>
<td>25.91&lt;sup&gt;a&lt;/sup&gt;</td>
<td>28.69&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Lipids (% DM)</td>
<td>8.41</td>
<td>4.81&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.22&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>PPL (% DM)</td>
<td>2.10</td>
<td>1.96</td>
<td>1.23</td>
</tr>
<tr>
<td>% of PPL&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PE</td>
<td>32.4</td>
<td>29.2</td>
<td>37.4</td>
</tr>
<tr>
<td>PI</td>
<td>20.9</td>
<td>13.9</td>
<td>16.3</td>
</tr>
<tr>
<td>PC</td>
<td>30.5</td>
<td>46.2</td>
<td>33.3</td>
</tr>
<tr>
<td>SM</td>
<td>16.2</td>
<td>10.7</td>
<td>13.0</td>
</tr>
</tbody>
</table>

MF using 0.8 um membrane

J Dairy Sci 2004, 87, 267
Other membrane techniques

• Counter diffusion
• Osmotic distillation
• Electrodialysis
• Ion-exchange
Counter diffusion

Separate small ions from large molecules
Hollow fibre cellulose diffusion tubes
Counter diffusion can produce 50% demineralisation which may represent 70% removal of monovalents
Osmotic distillation

Low pressure and low temp separation
Hollow fibre or spiral wound hydrophobic membrane
Electrodialysis

Uses electrical force to separate charged particles
Non-dairy uses of membrane technology

- Potable water desalination – RO
- Sea water desalination
- Juice processing
- Wine processing
Cleaning, sanitation & storage of membrane

- **CIP**
  - Flushing with water to remove loose dirt;
  - Circulatory cleaning with a caustic detergent;
  - Rinsing with water;
  - Circulatory cleaning with acid detergent;
  - Rinsing with water
Cleaning

- Factors affecting cleaning
  - Temperature
  - pH
  - Time
  - Type of soil
  - Membrane material
  - Water quality
  - Module design
  - Mechanics of cleaning
  - Types of cleaning agent
Sanitation and storage

- To minimise the bacterial attack
  - Sodium hypochlorite
  - Store in weak sodium hypochlorite, 5 ppm or sodium metabisulphite at 0.1% (short term) or 0.25% (long term)
# Typical cleaning procedure

<table>
<thead>
<tr>
<th>Operation</th>
<th>Agent</th>
<th>Feed pressure (Bar)</th>
<th>Temp °C</th>
<th>Duration (min)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Flushing until all product has been removed</td>
<td>Water/RO permeate</td>
<td>3.5</td>
<td>1.5</td>
<td>1-15</td>
<td></td>
</tr>
<tr>
<td>2. Caustic cleaning</td>
<td>0.5% Ultrasil - 25</td>
<td>3.5</td>
<td>1.5</td>
<td>75</td>
<td>12.6</td>
</tr>
<tr>
<td>3. Flushing out cleaning agent</td>
<td>Water/RO permeate</td>
<td>3.5</td>
<td>1.5</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>4. Acid cleaning</td>
<td>0.3% Ultrasil - 75</td>
<td>3.5</td>
<td>1.5</td>
<td>55</td>
<td>2.3</td>
</tr>
<tr>
<td>5. Flushing out cleaning agent</td>
<td>Water/RO permeate</td>
<td>3.5</td>
<td>1.5</td>
<td>75</td>
<td>2.3</td>
</tr>
<tr>
<td>6. Caustic cleaning</td>
<td>1.0% Ultrasil - 25</td>
<td>3.5</td>
<td>1.5</td>
<td>10</td>
<td>12.9</td>
</tr>
<tr>
<td>7. Flushing out cleaning agent</td>
<td>Water/RO permeate</td>
<td>3.5</td>
<td>1.5</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>8. Start production or proceed with step 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Disinfection</td>
<td>0.5% Oxonia</td>
<td>3.5</td>
<td>1.5</td>
<td>Room temp</td>
<td>10</td>
</tr>
<tr>
<td>10. Stop and leave the plant until next production</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Before next production flush out Oxonia</td>
<td>Water/RO permeate</td>
<td>3.5</td>
<td>1.5</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

N.B. All concentrations are weight percentages.
Glossary

- **Feed**
  - The solution to be concentrated or fractionated

- **Flux**
  - The rate of extraction of permeate measured in litres per square meter of membrane surface per hour (L/m²/h)

- **Membrane fouling**
  - Deposition of solids on the membrane, irreversible during processing
Glossary

- **Permeate**
  - The filtrate, the liquid passing through the membrane

- **Retentate**
  - The concentrate, the retained liquid

- **Concentration factor**
  - The volume reduction achieved by concentration, i.e. the ratio of initial volume of the feed to the final volume of concentrate
Glossary

- **Transmembrane pressure**
  - Pressure gradient between the upstream (retentate side) and downstream (permeate side)
  - Average pressure at the inlet and outlet of the equipment
  - 1 Bar = 0.1 MPa = 1 kg/cm² = 14.5 psi = 105 N/m²
Glossary

- **Coefficient of retention/rejection**
  - Quantitative measure for the characteristic ability of the membrane to retain solute species under specific operation parameters

\[
R_i = \frac{C_{ir} - C_{ip}}{C_{ir}} = 1 - \frac{C_{ip}}{C_{ir}}
\]

- \(R_i\) - coefficient of retention of a component \(i\)
- \(C_{ir}\) and \(C_{ip}\) are concentrations of \(“i”\) in retentate and permeate
Glossary

- Reynolds number
  - A dimensionless index used to describe the characteristic flow of liquids in pipes

\[
Re = \frac{Vd}{r} = \frac{Vd\rho}{\eta}
\]

- \(V\) – mean velocity \(V/A\) (m/s); \(d\) the pipe diameter of hydraulic (or equivalent) diameter (m); \(r\) is the Kinematic viscosity (m²/s);
- \(\eta\) is the absolute viscosity (Pa.s = kg/sm); \(\rho\) is the density of The flowing medium (kg/m³)

Re < 2000 - Laminar flow
Re > 2000 – Turbulent flow
Glossary

- **Diafiltration**
  - A modification of ultrafiltration in which water is added to the feed as filtration proceeds in order to wash out feed components which will pass through the membranes (in milk and whey – lactose and minerals)
Glossary

• **Concentration polarisation**
  - Solute build up
  - Reversible – velocity adjustment, pulsation, ultrasound, electric field

• **Membrane fouling**
  - Microbial adhesion, gel layer formation and solute adhesion
  - Irreversible