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# Membrane Fouling and Mitigation Strategies in Dairy Industry

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***Abstract***

Membrane Technology is widely used in Food processing and fouling remains a significant issue that affects efficiency. Fouling leads to the buildup of undesirable substances in the membrane that result in decrease in permeate flux. Membrane fouling can be categorized into three types- internal fouling, external fouling and fouling due to concentration polarization. There are several mitigation strategies used to deal with fouling in dairy industry that will ensure improved membrane effectiveness and quality production.

**Keywords:** Dairy industry, Membrane, Fouling, Mitigation

## Introduction

Membrane technology serves as a crucial tool in the Dairy industry offering the capability to separate, concentrate and refine different elements of milk and its derivatives through semi permeable membranes. These membranes act as filters, allowing specific molecules to pass while hindering others based on their size and characteristics. The primary objective is to enhance the quality, safety and shelf life of dairy products. The different types of membrane process are as follows:

1. **Microfiltration (MF):** Using membranes with larger pores ($10^{-1}$-$10^{1}$ µm), Microfiltration extracts sizeable particles like bacteria, yeast and certain fat globules from milk. This process is used for casein standardization and to extend shelf life of milk by reduction of bacteria and spores.
2. **Ultrafiltration (UF):** With smaller pores ($10^{-2}$-$10^{-1}$ µm) compared to Microfiltration, Ultrafiltration separates and concentrates milk proteins. It has also been successfully used to recover proteins from whey and concentrate / standardize milk proteins from smaller

compounds such as lactose, vitamins and minerals.

3. **Nanofiltration (NF):** Operating with even finer pores ($10^{-3}$-$10^{-2}$ µm), Nanofiltration is widely used for lactose concentration and demineralization. It allows monovalent ions (sodium and chloride) to pass through while partially rejecting divalent ions (calcium and magnesium). This process is integral for desalination and it enhance the sensory qualities of dairy products. It is used for partial demineralization and volume reduction of whey.
4. **Reverse Osmosis (RO):** Featuring the tiniest pores ($10^{-4}$-$10^{-3}$ µm), Reverse osmosis separates water from dissolved solutes, resulting in concentrated milk constituents which reduce shipping volumes and transportation costs. It is used for concentration or volume reduction of milk and whey, milk solids recovery and water reclamation.

Membrane processing offers various benefits to dairy processing including enhanced product quality, improved efficiency, decreased energy consumption and reduced reliance on heat treatments that might compromise product attributes. However, meticulous control over operational parameters and proper membrane maintenance are crucial to maintain consistent product quality and operational efficiency. Membrane processing benefits the dairy industry, but managing membrane fouling is crucial for consistent performance.

**Membrane fouling**

Membrane fouling is characterized as the buildup of undesirable substances either on the membrane's surface or within its pores, resulting a decrease in permeate flux. Membrane fouling can be categorized into three types: internal fouling, external fouling and fouling due to concentration polarization. Internal fouling refers to the accumulation of solutes and colloidal particles on the inside of the membrane pores resulting from deposition and adsorption processes. External fouling occurs when particles, colloids and macromolecules are deposited onto the surface of the membrane. Concentration polarization is the process where solutes and ions accumulate within the thin liquid layer that is situated close to the membrane's surface (Du et al., 2020).

**Foulants**

Membrane fouling is typically categorized based on the foulant type or where the fouling occurs. The primary groups of fouling agents encompass the following:

**1. Particulates**

These substances whether inorganic or organic particles/colloids, function as foulants that can physically obscure the membrane surface, pores or impede surface transport by creating a cake layer (Guo et al., 2012). Organic colloids consist of proteins, fats, carbohydrates, greases, oils,



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surfactants and bio-colloids. On the other hand, inorganic colloids encompass materials such as clay, silt, crystals, silica sediments as well as aluminum and iron precipitates formed due to incomplete treatments (AlSawaftah et al., 2021).

**2. Organic**

Organic fouling involves the gathering of natural organic matter (NOM) on the membrane's exterior. NOM encompasses humic acid (HA), carbohydrates (including polysaccharides), proteins, lipids along with various acidic and low molecular weight compounds like nucleic acids, amino acids, organic acids, carboxylic acid, alginate acid, cell components and polyacrylic polymers (Alkhatib et al., 2021).

**3. Inorganic**

Inorganic fouling typically pertains to the buildup of solid inorganic substances like calcium carbonate, calcium sulfate, silicate, sodium chloride, aluminum oxide, iron oxide, calcium phosphate, magnesium chloride, magnesium sulphate, ferric oxide and barium sulphate either on the membrane's exterior or within its pores. These inorganic constituents originate from the feed solution where they form scales through complex processes involving crystallization and transport mechanisms (Alkhatib et al., 2021).

**4. Biological fouling**

Biological fouling is characterized by the proliferation and buildup of bacteria or living microorganisms on the membrane's surface. Biofouling decreases membrane permeability, resulting in reduced productivity and eventually gives rise to prolonged operational challenges. Microorganisms capable of forming a biofilm on the membrane's surface include *Lactobacillus, Mycobacterium, Cytophaga, Flavobacterium, Bacillus and Pseudomonas.*

**Mitigation strategies**

It is described as the process of removing substances from a material that are not naturally a part of it. After undergoing membrane cleaning, the membrane should be physically, chemically and biologically pristine, ensuring it can deliver sufficient flux and effective separation capabilities. Numerous techniques exist for cleaning a fouled membrane which are as follows:

**1. Physical cleaning**

- **Sponge ball cleaning**: is a technique that entails using a sponge ball made from materials such as polyurethane to scrub contaminants off the membrane's surface. This method is commonly employed for membranes treating heavily polluted feed waters like industrial process water and wastewater.



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- **Alternate flushing**: It involves the application of alternating rounds of high-pressure cross-flow water, first from the permeate side to the feed side and then vice versa. This turbulence-inducing technique helps to dislodge adsorbed contaminants from the membrane's surface.
- **Backwashing:** Involves cleaning the membrane's clogged pores by generating a negative pressure difference across the membrane. This process induces turbulence on the membrane's surface, dislodging contaminants and clearing them from both the surface and pores.
- **Air flushing:** Is a technique similar to regular flushing but with the addition of air bubbles. This infusion of air amplifies the turbulence, effectively boosting the removal of deposits from the membrane during the flushing process (AlSawaftah et al., 2021**)**.

**2. Chemical cleaning**

This approach employs chemical substances that interact with contaminants, diminishing their attraction to the membrane's surface and facilitating deposit removal. Acids, bases, surfactants and chelating agents are among the frequently utilized chemicals. Lower pH cleaners are effective against colloidal particulates and inorganic scales while higher pH agents are preferred for eliminating organic fouling and microorganisms (AlSawaftah et al., 2021**)**.

**3. Non-conventional methods**

- **Ultrasonic cleaning:** It utilizes high-frequency sound waves to agitate the aqueous medium, effectively acting on the foulants adhering to the membrane surface. It can be seamlessly integrated into the filtration process without disrupting the production flow whereas backwashing or chemical cleaning requires a halt to normal operation. Membrane cleaning employs frequencies ranging from 21 to 620 kHz.
- **Electrical cleaning:** It involves the use of an electric field generated across a membrane by placing two electrodes on either side of it. This method is employed to enhance the permeation flux and prevent fouling in ultrafiltration (UF). This electrostatic force effectively lifts the deposits from the membrane surface and carries them away (Shi et al., 2014).

## Conclusion

Currently, the most significant problem and primary barrier to the widespread adoption of membrane process is the issue of membrane fouling. The occurrence of membrane fouling is influenced by various factors, including the composition of the membrane material and the characteristics of its surface. When membrane fouling takes place, it can lead to a decrease in permeate flow, an increase in feed pressure, lowered productivity and a shorter lifespan for membrane modules. Therefore, a key goal is to gain a better overall understanding of fouling in order to create appropriate pretreatment methods for the process sequence. This will ensure



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improved membrane effectiveness, better treatability and the production of effluent that meets acceptable quality standards.

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