Purification

Microfiltration

Microfiltration (commonly abbreviated to MF) is a type of physical filtration process where a contaminated fluid is passed through a special pore-sized membrane to separate microorganisms and suspended particles from process liquid. It is commonly used in conjunction with various other separation processes such as ultrafiltration and reverse osmosis to provide a product stream which is free of undesired contaminants.

General Principles

Microfiltration usually serves as a pre-treatment for other separation processes such as ultrafiltration, and a post-treatment for granular media filtration. The typical particle size used for microfiltration ranges from about 0.1 to 10 μm In terms of approximate molecular weight these membranes can separate macromolecules of molecular weights generally less than 100,000 g/mol. The filters used in the microfiltration process are specially designed to prevent particles such as, sediment, algae, protozoa or large bacteria from passing through a specially designed filter. More microscopic, atomic or ionic materials such as water (H2O), monovalent species such as Sodium (Na^+) or Chloride (Cl^-) ions, dissolved or natural organic matter, and small colloids and viruses will still be able to pass through the filter.

The suspended liquid is passed though at a relatively high velocity of around 1–3 m/s and at low to moderate pressures (around 100-400 kPa) parallel or tangential to the semi-permeable membrane in a sheet or tubular form. A pump is commonly fitted onto the processing equipment to allow the liquid to pass through the membrane filter. There are also two pump configurations, either pressure driven or vacuum. A differential or regular pressure gauge is commonly attached to measure the pressure drop between the outlet and inlet streams. See Figure 1 for a general setup.

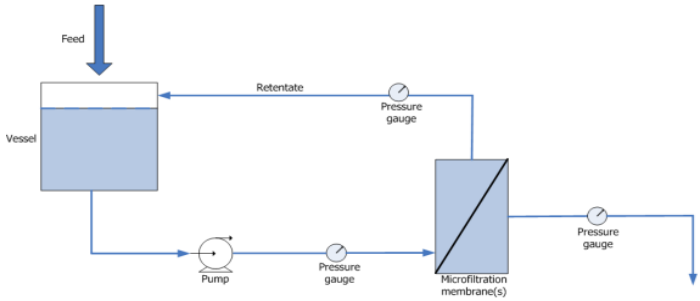

Figure 1: Overall setup for a microfiltration system

The most abundant use of microfiltration membranes are in the water, beverage and bio-processing industries (see below). The exit process stream after treatment using a micro-filter has a recovery rate which generally ranges to about 90-98 %.

Microfiltration Membrane Modules

Plate and frame (flat sheet)

Membrane modules for dead-end flow microfiltration are mainly plate-and-frame configurations. They possess a flat and thin-film composite sheet where the plate is asymmetric. A thin selective skin is supported on a thicker layer that has larger pores. These systems are compact and possess a sturdy design, Compared to cross-flow filtration, plate and frame configurations possess a reduced capital expenditure; however the operating costs will be higher. The uses of plate and frame modules are most applicable for smaller and simpler scale applications (laboratory) which filter dilute solutions.

Spiral-wound

This particular design is used for cross-flow filtration. The design involves a pleated membrane which is folded around a perforated permeate core, akin to a spiral, that is usually placed within a pressure vessel. This particular design is preferred when the solutions handled is heavily concentrated and in conditions of high temperatures and extreme pH. This particular configuration is generally used in more large scale industrial applications of microfiltration.

Fundamental Design Equations

As separation is achieved by sieving, the principal mechanism of transfer for microfiltration through micro porous membranes is bulk flow.

Generally, due to the small diameter of the pores the flow within the process is laminar (Reynolds Number < 2100) The flow velocity of the fluid moving through the pores can thus be determined (by Hagen-Poiseuille's equation), the simplest of which assuming a parabolic velocity profile.

$$v = \frac{D^2 * \Delta P}{32 * \mu * L}$$

Transmembrane Pressure (TMP)

The transmembrane pressure (TMP) is defined as the mean of the applied pressure from the feed to the concentrate side of the membrane subtracted by the pressure of the permeate. This is applied to dead-end filtration mainly and is indicative of whether a system is fouled sufficiently to warrant replacement.

$$v = \frac{P_F + P_C}{2} - P_P$$

Where

- P_f is the pressure on the Feed Side
- P_c is the pressure of the Concentrate
- P_p is the pressure of the Permeate

Permeate Flux

The permeate flux in microfiltration is given by the following relation, based on Darcy's Law

$$J_v = \frac{1}{A_M} * \frac{dV}{dt} = \frac{\Delta P}{\mu * (R_u + R_c)}$$

Where

- R_u = Permeate membrane flow resistance $(m-1)$
- R_c = Permeate cake resistance $(m-1)$
- μ = Permeate viscosity (kg m-1 s-1)
- ΔP = Pressure Drop between the cake and membrane

The cake resistance is given by:

$$R_c = r * \frac{V_S}{A_m}$$

Where

- r = Specific cake resistance (m-2)
- Vs = Volume of cake (m3)
- AM = Area of membrane (m2)

For micron sized particles the Specific Cake Resistance is roughly

$$r = \frac{180 * (1 - \epsilon)}{\epsilon^3 * d_s^2}$$

Where

- ε = Porosity of cake (unitless)
- d_s = Mean particle diameter (m)

Rigorous design equations

To give a better indication regarding the exact determination of the extent of the cake formation, one-dimensional quantitative models have been formulated to determine factors such as

- Complete Blocking (Pores with an initial radius less that the radius of the pore)
- Standard Blocking
- Sublayer Formation
- Cake Formation

Ultrafiltration

Ultrafiltration (UF) is a variety of membrane filtration in which forces like pressure or concentration gradients lead to a separation through a semipermeable membrane. Suspended solids and solutes of high molecular weight are retained in the so-called retentate, while water and low molecular weight solutes pass through the membrane in the permeate. This separation process is used in industry and research for purifying and concentrating macromolecular (10^3 - 10^6 Da) solutions, especially protein solutions. Ultrafiltration is not fundamentally different from microfiltration. Both of these separate based on size exclusion or particle capture. It is fundamentally different from membrane gas separation, which separate based on different amounts of absorption and different rates of diffusion. Ultrafiltration membranes are defined by the molecular weight cut-off (MWCO) of the membrane used. Ultrafiltration is applied in cross-flow or dead-end mode.

Applications

Industries such as chemical and pharmaceutical manufacturing, food and beverage processing, and waste water treatment, employ ultrafiltration in order to recycle flow or add value to later products. Blood dialysis also utilizes ultrafiltration.

Drinking water

Drinking water treatment 300 m³/h using ultrafiltration in Grundmühle waterworks (Germany)

UF can be used for the removal of particulates and macromolecules from raw water to produce potable water. It has been used to either replace existing secondary (coagulation, flocculation, sedimentation) and tertiary filtration (sand filtration and chlorination) systems employed in water treatment plants or as standalone systems in isolated regions with growing populations. When treating water with high suspended solids, UF is often integrated into the process, utilising primary (screening, flotation, filtration) and some secondary treatments as pre-treatment stages. UF processes are currently preferred over traditional treatment methods for the following reasons:

- No chemicals required (aside from cleaning)
- Constant product quality regardless of feed quality
- Compact plant size
- Capable of exceeding regulatory standards of water quality, achieving 90-100% pathogen removal

UF processes are currently limited by the high cost incurred due to membrane fouling and replacement. Additional pretreatment of feed water is required to prevent excessive damage to the membrane units.

In many cases UF is used for pre filtration in reverse osmosis (RO) plants to protect the RO membranes.

Protein concentration

UF is used extensively in the dairy industry; particularly in the processing of cheese whey to obtain whey protein concentrate (WPC) and lactose-rich permeate.[5][6] In a single stage, a UF process is able to concentrate the whey 10-30 times the feed.

The original alternative to membrane filtration of whey was using steam heating followed by drum drying or spray drying. The product of these methods had limited applications due to its granulated texture and insolubility. Existing methods also had inconsistent product composition, high capital and operating costs and due to the excessive heat used in drying would often denature some of the proteins.

Compared to traditional methods, UF processes used for this application:

- Are more energy efficient
- Have consistent product quality, 35-80% protein product depending on operating conditions
- Do not denature proteins as they use moderate operating conditions

The potential for fouling is widely discussed, being identified as a significant contributor to decline in productivity. Cheese whey contains high concentrations of calcium phosphate which can potentially lead to scale deposits on the membrane surface. As a result substantial pretreatment must be implemented to balance pH and temperature of the feed to maintain solubility of calcium salts.