Energy Efficient
Crossflow Filtration

Introduction

The principle of crossflow filtration can be seen from figure 1. The product to be filtered is passed over a porous surface, which can be tubular or flat in form.

The speed at which the product passes across the surface tends to maintain the direction of flow whilst the filtrate passes through the membrane by virtue of a pressure differential (the Trans-Membrane-Pressure - TMP). A multi-channel membrane element is shown in figure 2.

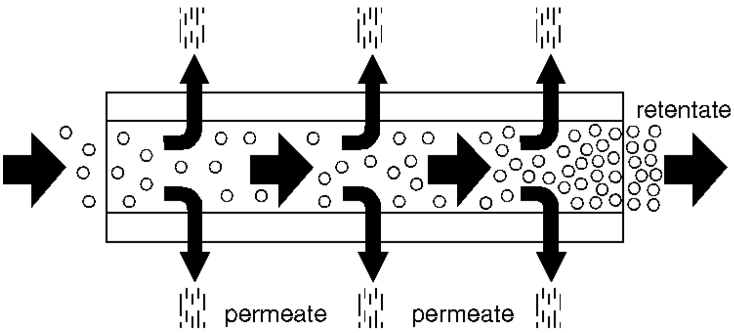

Fig 1. Principle of Crossflow Filtration

If the speed is reduced or the TMP increased beyond optimum operating parameters then the suspended solids will tend to block, or blind, the pores of the membrane. The pore sizes of membranes range from reverse osmosis (RO) through to ultrafiltration (UF) to microfiltration (MF).

In the past, crossflow filtration systems have been restricted in their applications to medium or high-value products because of the relatively high pumping energy requirements. In order to achieve the necessary crossflow velocity a high crossflow volume is required and hence high-powered pumping systems.

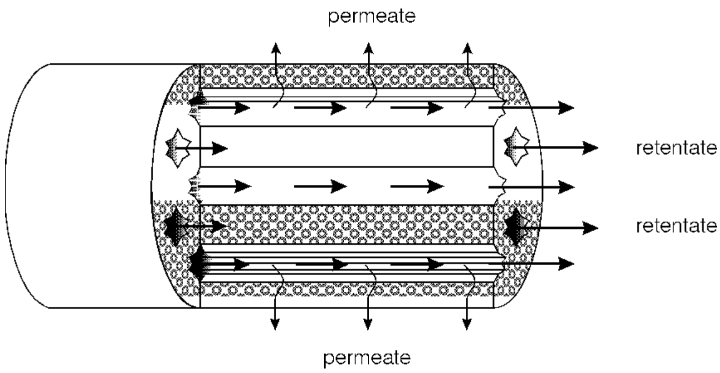

Fig 2. Multi-Channel Membrane

A crossflow velocity in the region of 2 to 6 m/s is generally considered necessary to provide the surface shear on the membrane to break up the fouling layer. The optimum velocity depends on the product being processed: its viscosity, suspended solids, etc.

Diameter/Circumference Relationship – Tubular Membranes

With a constant crossflow velocity it is beneficial to design a system with the maximum of circumference (membrane area) and the minimum cross-sectional area (retentate flow). In a circular design the circumference increases in direct proportion to the diameter:

$$Circumference = \pi D$$

Whereas, the cross sectional area increases as the square of the diameter:

$$Cross\text{-}sectional\ area = \pi D^2/4$$

Therefore, it is desirable to have a greater number of the smallest diameter flowpaths (of the minimum acceptable

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diameter considering particle size and viscosity) rather than a large diameter single flowpath requiring high crossflow volumes at a similar crossflow velocity.

An Energy Efficient Alternative Configuration

The crossflow volume (m^3/h) equals the cross sectional area of the flowpath (m^2) multiplied by the average velocity (m/hr).

Crossflow volume (m^3/h) =
cross sectional area (m^2) x average velocity (m/s) x 3600

To reduce the crossflow volume (and hence the pumping energy), whilst maintaining the velocity, the appropriate variable to decrease is the cross sectional area of the flowpath.

Typically, flowpaths have been circular in section, although square sections have also been produced. Initially thoughts suggested the fitting of a turbulator within the circular flowpath. This would, theoretically, introduce turbulence with subsequent reduction in fouling. The presence of a turbulator would also reduce the cross sectional area and hence the pumping energy input. The main problem with a turbulator is locating it within the membrane and the introduction of crevices. Rubbing movement of the turbulator against the membrane was also considered a problem. Having rejected turbulators, alternatives were sought. This resulted in the star shaped flowpath design. From this configuration, *figure 3*, the following enhanced features result:

- Reduced Cross Sectional Area
- Induced turbulence / Reynolds number
- Increased perimeter (increased membrane area)
- Crossflow pressure drop

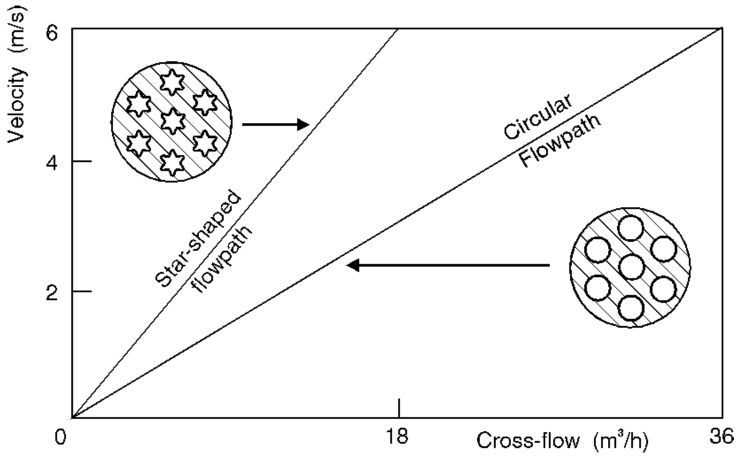

Fig 3. Effect of Crossflow Channel Section on Crossflow Volume

Reduced Cross-Sectional Area

With a star shape cross section having an inner tip radius approximately half the outer tip radius, the cross-sectional area is reduced by nearly 50%. Maintaining the same velocity as for a circular flowpath, the crossflow volume, therefore, is reduced by nearly 50% and the pump energy input is reduced by a similar amount.

This reduction may not appear significant for small systems but on larger systems considerable savings can be made. In the processing of the low value products, such as waste materials, the reduction in pumping power may mean the difference in the viability of using crossflow filtration.

Induced Turbulence/Reynolds Number

The design of membranes is such that a turbulent flow condition exists to break up the fouling layer at the surface of

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the membrane. This requirement is similar to that demanded by heat exchangers, both tubular and plate type, to increase heat transfer co-efficients. For a circular flowpath a minimum Reynolds number in the region of 2000-3000 is generally considered necessary to pass from laminar to turbulent flow at the interface.

$$\text{Reynolds Number} = \frac{\text{Density} \times \text{Average Velocity} \times \text{Diameter}}{\text{Viscosity}}$$

Returning to the heat exchanger comparison, various systems exist to lower the point where laminar flow changes to turbulent flow. On a tank cooling jacket where dimples are introduced into the jacket surface the change from laminar to turbulent flow can occur at a Reynolds number in the region of 400-800 with a corresponding drop in crossflow velocity. Similarly for a plate heat exchanger with turbulence-inducing surfaces, the change from laminar to turbulent flow occurs at 150-200 resulting in a dramatic reduction in crossflow velocity.

The precise Reynolds number required to introduce turbulent conditions through the star shape flowpath is believed to be in the range 1000-1500, although the actual value has yet to be evaluated. Theoretically, this dramatically reduces the crossflow volume needed. Combining this with the reduction in crossflow volume, due to the reduced flowpath cross sectional area, it is anticipated an overall reduction of crossflow volume of 70-80% is possible. This figure will obviously vary with the type of fluid being filtered.

Increased Perimeter

The perimeter of the chosen star shape is approximately 15% greater than a circle of equivalent outer tip diameter. The increased perimeter, therefore, increases the membrane surface area by 15% per unit length.

Yet another feature assisting in reducing energy input. Generally, the single membranes are bundled together in parallel and installed in a housing.

Crossflow Pressure Drop

Although there are reductions in energy by virtue of the reduced crossflow volumes, there is of course, a slight increase in pressure drop per unit length because of the reduced cross sectional area. Tests on water show a pressure drop increase of about 15%. However, as previously discussed, the crossflow velocity can be reduced dramatically with the star shape while maintaining the necessary turbulence to break up the membrane fouling layer. The actual pressure drop, therefore, is considerably less per unit length, as a result of the reduced crossflow velocity, than that of the comparable circular flowpath.

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