GE Healthcare
Life Sciences

Process Operating Considerations

Effect of Operating Parameters on Membrane Flux

Temperature

Water flux and, most often, process flux will increase with increasing temperature. Clean water flux will vary linearly as a function of water viscosity, and over a narrow range (i.e., 25 °C ± 10 °C [77 ° F ± 20 °F]) changes in water viscosity may be approximated by the ratio of temperature change in degrees Fahrenheit. Thus, water flux or process flux measurements between runs may be easily compared at a standard temperature, using the equation:

$$\text{Temperature Corrected Flux} = (\text{Flux})T_2 \times \frac{T_1}{T_2}$$

where, T_1 = Reference temperature (e.g., 77 °F)
T_2 = Actual Temperature (° F)

For example, On a new cartridge, the measured clean water flux is 40 lmh at 18 °C (64.4 °F).

Temperature Corrected Flux =

$$40 \text{ lmh} \times \frac{77\ °\text{F}}{64.4\ °\text{F}} = 47.8 \text{ lmh}$$

Process flux will also increase with temperature. The degree of process flux improvement is less predictable than with clean water since both a “gel” layer and a “fouling” layer on the membrane surface contribute to flux resistance. With some streams, one will observe a linear flux improvement with temperature. With others, a step-wise improvement may occur after a “critical” temperature is reached.

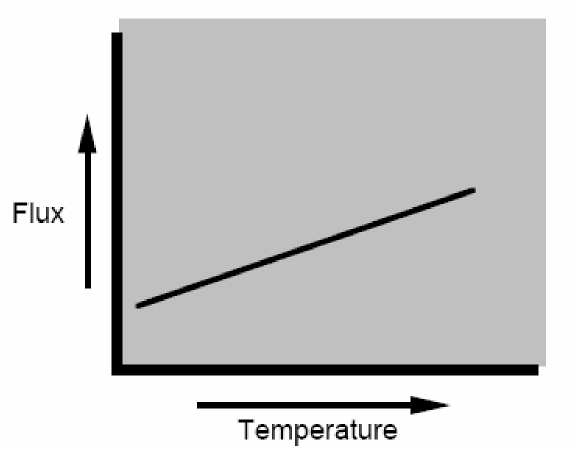
As a general rule, operation should be at the highest temperature acceptable for the membrane, given the constraints of feed stream pH and the operating pressure.

Examples:

When processing at 15 °C...
the clean water flux will be about 75% of the flux at 25 °C.

When processing at 35 °C...
the clean water flux will be about 125% of the flux at 25 °C.

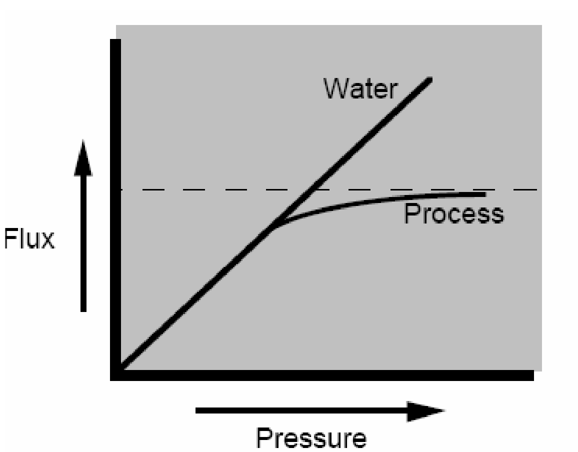
Process flux may behave differently.



Transmembrane Pressure

Water flux will increase linearly with increasing transmembrane pressure. Process flux will typically increase as a function of transmembrane pressure. However, depending on the recirculation rate, the improvement in flux may become asymptotic since "gel" layer resistance to flux will increase from compaction. Control of permeate backpressure (restricting permeate flow rate) may reduce the tendency for fouling in the initial stages of a concentration, providing an overall higher average flux rate (see below for more details on "Permeate Flow Control")

Transmembrane Pressure = $[(P_{inlet} + P_{outlet})/2] - P_{permeate}$



Recirculation Rate

Recirculation rate (feed velocity) will have little, if any, effect on the membrane's clean water flux since there is ideally neither a "gel" layer nor a "fouling" layer to restrict permeation. On the other hand, the basic premise of cross flow filtration is that increased velocity will reduce "gel" layer formation, lowering the resistance to permeation and, hence, improve flux.

Thin feed flow channel devices (i.e., hollow fibers, spiral-wound cartridges and plate-andframe devices) all operate in laminar flow. Increasing the recirculation rate will increase the wall shear and typically enhance the rate of filtration. However, the pressure losses across thin channel devices which become higher with increased recirculation limit the practical degree to which feed velocity can be raised. In general, if high velocities are to be achieved with thin channel devices, the feed flow path should be as short as practical. For this reason, GE Healthcare offers a full range of hollow fiber membrane cartridges with nominal one foot (30 cm) flow path lengths (Housing Sizes 3, 4, 5, 8, 35 and 45).

Fouling streams do not respond well to feed dilution and tend to reach low, steady-state flux levels which are less dependent on feed concentration. Higher feed flow rates, exhibiting a shear rate of at least 8,000 sec-1, should be utilized.

Low-fouling streams exhibit stable flux rates over time with low recirculation rates. The flux of low-fouling streams is basically concentration-dependent. Thus upon feed stream dilution, the permeate rate will increase and approach the starting performance level. A feed flow rate which provides an intermediate shear rate, on the order of 4,000 sec-1 to 8,000 sec-1, is a good starting point for processing low fouling streams.

Shear-sensitive streams contain fragile components (e.g., infected cells, viruses) which may be damaged by high recirculation rates or high temperature. Recirculation rates which provide shear rates on the order of 2,000 to 4,000 sec-1 are recommended for shear sensitive streams.

See Table below in "Feed Stream Flow Rate" for specific volumetric flow rates that correspond to these various shear velocities for various sizes of hollow fiber cartridges.

Resistance to permeation is a function of the membrane pore size, feed stream components, and the degree to which gel layer formation and fouling layer formation occur. **Increasing the feed stream recirculation rate will, as a general rule, reduce gel layer thickness and increase flux.**

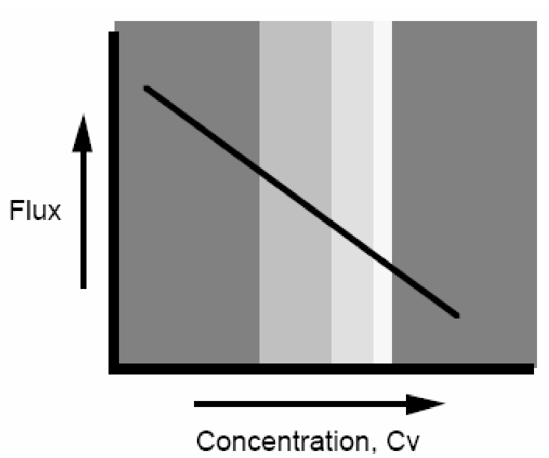
Volumetric Concentration—System Conversion Relationship

Cv	*y*
1X (Vp = 0)	0%
2X	50%
5X	80%
10X	90%
20X	95%
50X	98%

$$Cv = \frac{Vo}{Vo - Vp} \qquad y = 1 - \frac{1}{Cv}$$

where,

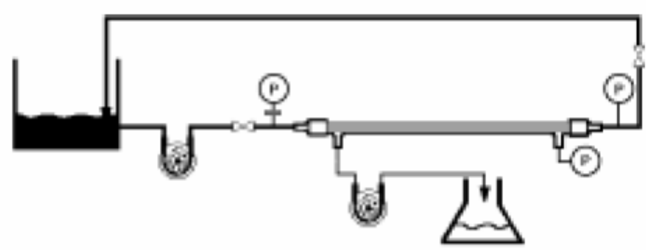
Cv = Volumetric Concentration Factor
Vo = Original Feed Volume
Vp = Volume of Permeate Collected
y = System Conversion, %



Concentration—Process flux is highly dependent on feed components and overall solids concentration. As expected, flux declines with concentration. The rate of decline generally follows a straight line in a semi log plot of flux (linear scale) versus concentration factor (log scale).

Time—Flux declines with time, even with "clean" water. The influence of time on the rate of flux decline may, however, be insignificant compared to the effect of concentration. A rapid flux decline, while processing a stream in "total recycle" (i.e., no concentration) indicates either the recirculation rate is too low or "bad actor" foulants are present. Flux decline as a function of time may also occur with a process stream due to gel layer compaction.

Permeate Flow Control—When a product is being clarified through a microfiltration membrane or other "high flux" membranes, clients often experience enhanced product recovery and abbreviated process times by controlling the permeate pressure or by controlling the permeate flow rate. Pressure control requires a pressure gauge and valving on the permeate line. Flow control, while achievable manually by constantly monitoring the flow rate, is most easily performed by positioning a metering pump on the permeate line. With either method, the initial permeate flow should be set at roughly 40% of the fully open, non-controlled permeate rate after 5 to 10 minutes operation. If, as the concentration proceeds, the permeate rate falls below this mark, the backpressure may be reduced or the metering pump by-passed.

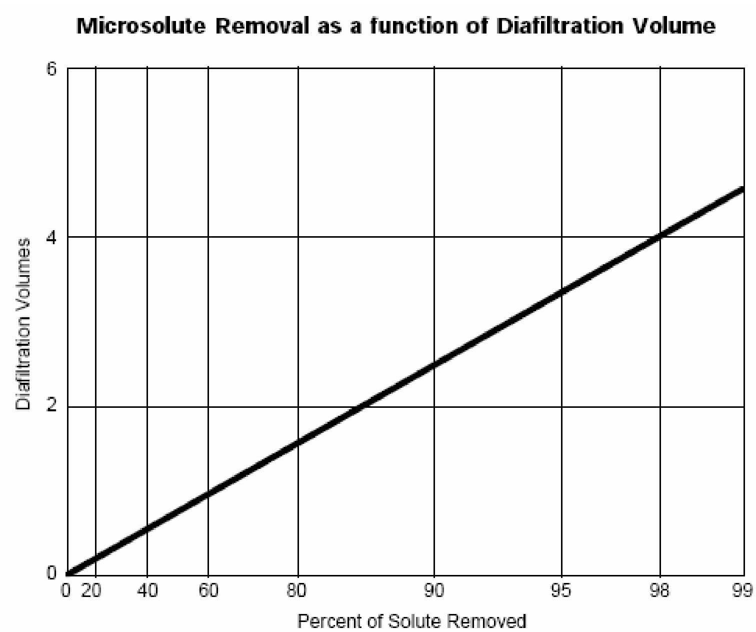


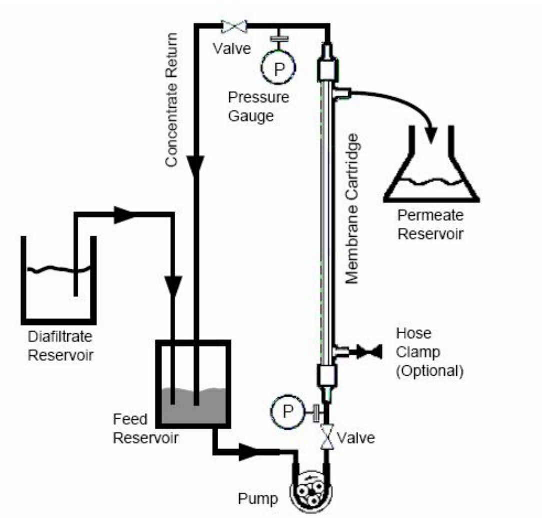
For high flux membranes, permeate flow control is an effective means of improving flow stability and increasing overall productivity.

1. Inlet pressure gauge should be glycerine filled or mechanically dampened.
2. If feed pump has variable speed control, inlet valve may be omitted.
3. Gauge on permeate port should read Pressure/Vacuum. Maintain positive pressure.

Diafiltration

Diafiltration is a unit operation incorporating ultrafiltration membranes to efficiently remove salts or other microsolutes from a solution. The microsolutes are so easily washed through the membrane with the permeated diafiltration water that for a fully permeating species, about 3 volumes of diafiltration water will eliminate 95% of the microsolute. It is interesting to note that net effective removal of the microsolute is solely dependent on the volume of ultrafiltrate produced and not on the microsolute concentration. A graph of microsolute removal (assuming 0% rejection by the membrane) is provided.





Simplified System Schematic for Continuous Diafiltration

1. Pressure Gauges (particularly the inlet gauge) should be glycerin filled or mechanically dampened.
2. If feed pump has variable speed control, inlet valve may be omitted.
3. Second permeate port may be used or blocked.
4. Diafiltrate is drawn into the feed reservoir at the same rate that permeate is withdrawn.
5. Initial concentration, followed by diafiltration will minimize diafiltrate volume but may maximize total filtration time. On the other hand, initial diafiltration followed by concentration will maximize diafiltrate volume. Partial concentration/diafiltration/final concentration may minimize total filtration time with a mid-range volume of diafiltrate solution. Thus, optimization of the process is required on a case-by-case basis.

Feed Stream Flow Rate

The feed stream flow rate has a major effect on permeate flux. Guidelines for the recirculation flow rate through the cartridges are provided in terms of cartridge size, lumen diameter and shear rate. The pressure drop across the length of a cartridge is a function of the feed flow rate and may be used in lieu of a flow meter to determine the recirculation rate.

For laboratory-scale cartridges, measuring both the permeate and retentate flow rates with a stopwatch and graduated cylinder and simply adding them together will provide the feed flow rate.

Nominal Feed Stream Flow Rates					
Housing Size	Nominal Lumen ID (mm)	Shear Rate ~2000 sec-1 (liters/min)	Shear Rate ~4000 sec-1 (liters/min)	Shear Rate ~8000 sec-1 (liters/min)	Shear Rate ~16000 sec-1 (liters/min)
3, 3M, 3X2, 3X2M	0.25	0.05	0.11	0.23	0.4
	0.5	0.06	0.12	0.25	0.5
	0.75	0.1	0.2	0.4	0.8
	1	0.15	0.3	0.6	1.2
4, 4M, 4X2, 4X2M	0.25	0.19	0.38	0.76	1.5
	0.5	0.3	0.6	1.2	2.4
	0.75	0.4	0.8	1.5	3
	1	0.6	1.2	2.5	5
5, 6	0.25	0.65	1.3	2.5	5
	0.5	1.1	2.1	4.3	8.6
	0.75	1.4	2.8	5.6	11.2
	1	2	4	8	16
8, 9	0.25	1.6	3.2	6.4	12.8
	0.5	2.7	5.4	10.6	21.5
	0.75	4.4	8.8	18	35
	1	6.1	12.2	24.5	49
35, 35STM, 35SMO, 55, 55R, 55STM, 55SMO, 75, 75R	0.25	4.5	9	18	36
	0.5	6.6	13.2	26	53
	0.75	10	20	40	80
	1	15	30	60	120
45, 65, 85	0.5	14	28	55	111
	0.75	19	39	77	154
	1	31	61	122	245
152M, 154M	0.5	30	60	120	240
	1	70	140	280	560

Shear rates and flow rates are directly proportional. Highly fouling streams may require flow rates equivalent to a shear rate well in excess of 8,000 sec-1. Shear rates based on viscosity of 1 cp.

imagination at work

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