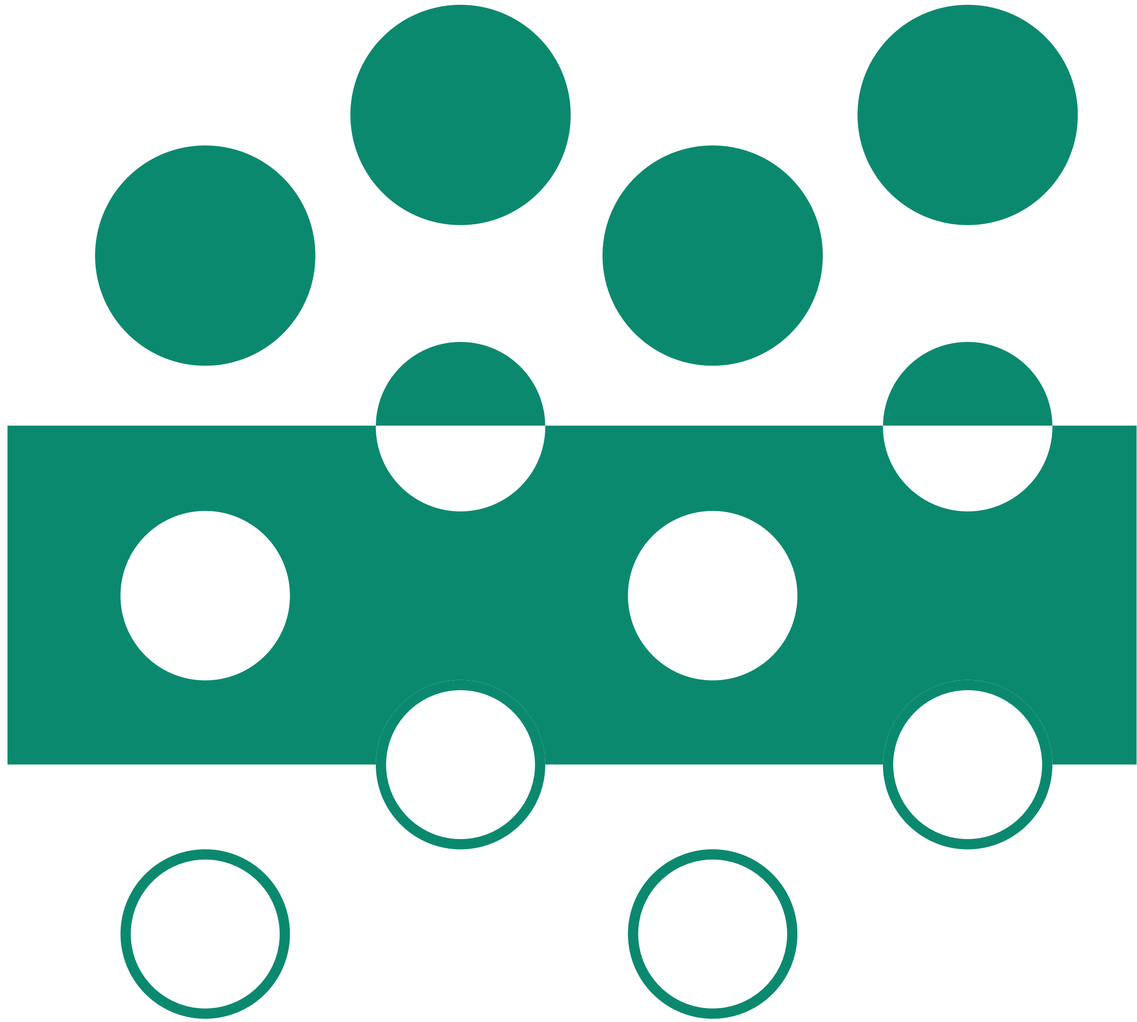
Hollow fiber cartridges for membrane separations

Operating handbook



cytiva

Operating precautions

1. **Flush** ultrafiltration (UF) cartridges prior to use to remove preservative solution and **measure** clean water flux. Follow instructions on pages 9 and 10.
2. Autoclavable and steam-in-place UF cartridges will benefit from a **clean water soak** following first rinse, the longer the better.
3. Membrane water flux may be significantly affected by water quality and temperature as well as wetting and cleaning procedures. **Review** pages 9, 10, 12 and 16.
4. Do **not** allow UF cartridges to dry out.
5. Do **not** shock membrane cartridges during handling nor expose to pressure surges during operation.
6. Do **not** shock membrane cartridges with rapid temperature changes. Increase or decrease temperature gradually (nominally 1°C/minute).
7. Do **not** clamp cartridges too tightly.
8. **Loosen** clamps before autoclaving.

Contents

Principles and methodology handbooks from Cytiva

Cytiva offers a wide range of handbooks that provides practical tips and in-depth information about common methodologies used in the lab. Visit cytiva.com/handbooks to view the complete list and download your copies today.

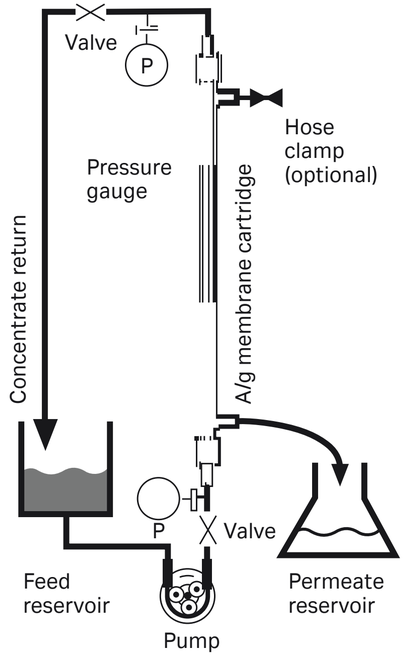
Cross flow filtration apparatus and glossary of terms

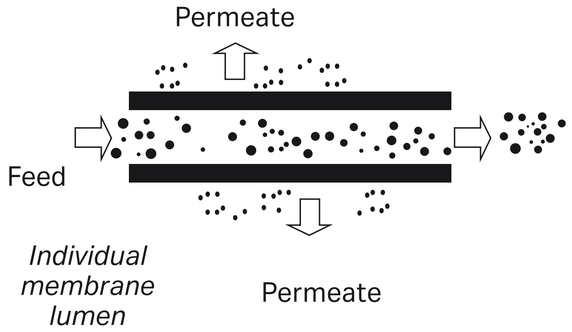
Cytiva ultrafiltration (UF) and microfiltration (MF) membrane cartridges are provided with a wide range of hollow fiber and tubule lumen diameters, membrane pore sizes, surface areas and dimensions. Each cartridge contains a bundle of polysulfone fibers or tubules potted in parallel within a plastic housing.

These cartridges are operated in a cross flow mode. In sharp contrast to single pass filtration, **cross flow** involves recirculation of the **feed stream** pumped across the membrane surface. The "sweeping action" created by fluid flow across the membrane surface promotes consistent productivity over the long term.

In operation, as the feed stream is pumped through the membrane cartridge, the **retentate**, including species excluded by the membrane pores, continues through the recirculation loop while the **permeate**, including solvent and solutes transported through the membrane pores, is collected on the shell side of the cartridge.

For laboratory or pilot applications, a basic manual control system consists of a pump, feed reservoir, permeate collection reservoir, pressure gauges, and valving (see below). Permeate connections are typically of flexible tubing.





Simplified system schematic

1. A prefilter with a 200 µ rating may be desirable to protect rotary lobe pumps.
2. Pressure gauges (particularly the inlet gauge) should be glycerine filled or mechanically dampened.
3. If feed pump has variable speed control, inlet valve may be omitted.
4. Second permeate port may be used or blocked.

All Cytiva polysulfone membranes and cartridge materials are usp xxvii class 6 safety tested. Cytiva provides both an integrity test procedure guide and a validation information booklet to assist customers with validation and continual quality assurance of our products.

Peristaltic pumps are commonly used in laboratory situations, while centrifugal pumps can be utilized in industrial-scale systems. For sanitary operations, either peristaltic or rotary-lobe pumps are generally preferred.

The membrane cartridge may be operated in **either** a **horizontal or vertical position**. When the concentrate stream is the product of interest, vertical orientation will allow better drainage and higher recovery. Higher concentrations may also be reached when the void volume of the system is minimized by utilizing short tubing lengths and by discharging the feed stream from a conical bottom tank.

One permeate port may be capped (blocked) to minimize system tubing. For UF cartridges in vertical orientation, either permeate port may be left open. However withdrawal of permeate from the lower port will permit more complete drainage of the permeate-side. With MF cartridges, the MF permeate should be withdrawn from the upper port to minimize transmembrane pressure.

Glossary of terms

Cross flow
Sweeping action created by fluid flow across the membrane (also called tangential flow).

Feed stream
Bulk solution to be processed via ultrafiltration or microfiltration (also called process solution).

Retentate
Solution containing species retained by the membrane (also called concentrate or reject).

Permeate
Solution containing solvent and solutes passing through the membrane (also called filtrate or ultrafiltrate).

Start-up procedures

Ultrafiltration

Ultrafiltration cartridges should be started-up with the **permeate ports closed**, allowing the cross flow velocity to be established prior to permeate withdrawal. If a positive displacement pump is used, both the feed inlet valve and the retentate valve should be wide open. If a centrifugal pump is used, the feed inlet valve should be cracked open and the retentate valve should be open. The ideal system includes a variable speed control on the pump motor. This allows the recirculation flow rate to be increased gradually until the specified pressure drop is achieved.

After turning on the pump, the inlet valve should be opened and the retentate valve slowly closed to establish the preferred feed flow rate and/or pressure. If necessary, the inlet pressure may be reduced by adjusting the feed inlet valve or by installing a by-pass loop on the pump outlet. Since feed flow rate is proportional to the feed-to- retentate pressure drop along the length of a cartridge, the tables on page 31 may be used to estimate feed flow rates.

When the correct inlet pressure and feed flow are established, the permeate lines should be opened.

Concentrate return to the feed reservoir should be below the liquid level to avoid splashing, foaming and excess air generation which could cavitate the pump.

Additional consideration for high viscosity feed streams

Use of a high recirculation rate for a few minutes to “fast flush” the lumen side of the fibers will assure air removal. This is especially important when processing viscous streams to maintain even flow distribution within the cartridge. Since a highly viscous stream cannot be pumped at high flow rates due to pressure drop considerations, one should circulate either water or a buffer solution prior to introducing the viscous feed material.

Microfiltration

Special consideration should be given to start-up of high flux microfiltration membranes to avoid rapid gel layer formation and its associated flux decline. In almost all cases, the **permeate ports should be blocked during startup**, so that the cross flow velocity can be fully established. If possible, either water or buffer solution should be circulated initially within the system followed by feed stream introduction.

The inlet pressure should be as low as possible (<10 psig), given the constraints of recommended recirculation rates and the system's pump characteristics, to prevent pore plugging by small particulates or cell fragments. Outlet (retentate) pressure should be ~0 psig.

Once the cross flow has been established, permeate withdrawal is begun by opening one or both permeate ports on the cartridge. If very rapid flux decline is observed with the permeate ports fully open (i.e., permeate discharged at atmospheric pressure [0 psig]), then subsequent trials should be run with backpressure on the permeate line(s) and a controlled permeate discharge rate in an effort to obtain stable flux levels and improve the overall long term system productivity.

New cartridge conditioning and water flux measurement

Ultrafiltration

Removal of glycerol preservative

Ultrafiltration (uf) membrane cartridges are pre-treated with an **alcohol/glycerol** solution within the pore structure to prevent drying of the membrane. *This mixture enhances wetting but may cause the fibers to appear wavy*. Trace amounts of alcohol (ipa) may remain when the cartridges are shipped. The glycerol must be thoroughly rinsed from the cartridge prior to use. In addition to preventing drying, the glycerol minimizes entrained air within the pore structure of the membrane wall which may become "locked-in" reducing permeability until the air has been displaced by liquid. Glycerol removal and "wetting out" will occur simultaneously when performing the new cartridge rinsing procedure. Most clients elect to sanitize both UF and MF membranes prior to use. Refer to page 20 for complete details.

New cartridge rinsing procedure [recommended for all uf membranes]

The new cartridge rinsing procedure should be performed on all ultrafiltration cartridges.

1. Use clean water (WFI or 10,000 NMWC UF permeate).
2. Adjust average transmembrane pressure of cartridge to 15 psig for 1,000 NMWC and 3,000 NMWC pore sizes; 10 psig for 5,000 NMWC through 30,000 NMWC pore sizes; and 5 psig for larger pore sizes.
3. Be certain retentate flow rate is at least 1/10th of the permeate flow.
4. Discharge both retentate and permeate to drain.
5. Use room temperature or warm (up to 50°C) water for rinsing. Cold water will be less effective. Addition of 100 ppm NaOCl to flush water will enhance glycerol removal.
6. Continue rinsing for 90 minutes. Make sure NaOCl has been thoroughly rinsed out before introducing process solution.

Alcohol pre-treatment procedure

Alcohol pre-treatment may be used to enhance water flux of "tight" (30,000 NMWC and lower) UF membranes. For best results, follow procedure below before water contact, extending time of soak to overnight. If cartridge has already been exposed to water, shake out excess and then extend soak time to overnight. Either isopropyl alcohol (IPA) or ethanol may be used.

1. Fill cartridge with 100% alcohol for one hour. For best results, soak cartridge overnight. Take appropriate precautions with use of alcohol. Be certain that both the lumen side and the shell side of the cartridge are filled and that air has been displaced.
2. If facilities are in place, this procedure will be more effective if the alcohol is pumped through the cartridge for at least 10 minutes prior to soaking.
3. To remove alcohol, rinse with clean water according to the new cartridge rinsing procedure.
4. The alcohol solution may be saved and reused several times before discarding.

Autoclavable/steam-in-place cartridges [extended pre-soak]

Before sterilizing UF cartridges in an autoclave or in an SIP sterilization procedure, the cartridge must be fully rinsed of glycerol. If UF cartridges are to be autoclaved or steam sterilized, a pre-soak is recommended as an adjunct to the flushing procedure.

1. Rinse cartridge per new cartridge rinsing procedure, above, for 30 minutes.
2. Soak cartridge in clean water, the longer the better. Be certain that both the lumen side and shell side of the cartridge are filled and that air has been displaced.
3. Rinse cartridge per new cartridge rinsing procedure, above, for 30 minutes.

Microfiltration

Although microfiltration (MF) membrane cartridges are shipped dry, without preservative solutions, it is prudent to rinse cartridges before first process exposure or heat sterilization. Follow New Cartridge Rinse Procedure for at least 5 minutes at 5 psig (0.3 barg) inlet pressure.

Clean water flux evaluation

After rinsing, the next step with a new cartridge is to obtain baseline data on clean water flux. These data should be taken under *easily repeatable conditions* so that comparisons with water flux data after cleaning cycles can be made directly.
The parameters to monitor are:

- Water temperature
- Cartridge inlet pressure
- Cartridge outlet pressure
- Permeate pressure

"Clean" water, which is defined as 10,000 NMWC (or tighter) ultrafiltration permeate, or WFI, is required to assure contaminants are not present which could negatively impact membrane performance.

Water flux is most reliably measured at low inlet pressure. When using UF permeate or WFI, minimal cross flow is required, and the retentate valve need only be cracked open to ensure elimination of air trapped on the lumen-side.

With high flux Cytiva MF and ≥500,000 NMWC UF membranes, parasitic pressure drop will occur on the permeate side of the cartridge during clean water flux determinations unless the inlet pressure is very low (typically <5 psig) and there are no restrictions (flowmeters, reducers, etc.) on the permeate piping. Thus, while a laboratory-scale membrane operating under “ideal” conditions might exhibit a water flux of 50 liters per square meter of membrane surface area per hour per psi [lmh/psi], the same membrane in a process-scale cartridge might exhibit a clean water flux of 25 lmh/psi. This difference between the “ideal” case and the "real world" is true of all membrane cartridges, regardless of manufacturer.

Again, as long as the operating conditions and piping are kept consistent, water flux data over the life of the cartridge can be monitored and compared.

Low water flux values may be due to contaminants in feed water, ineffective cleaning, low water temperature and/ or entrained air within the membrane pore structure. If entrained air is suspected, follow this simple procedure:

Connect cartridge in a vertical position to a recirculation pump. At start, lower permeate port should be closed, upper permeate port open, reject valve wide open. The wetting solution is clean water (10,000 NMWC UF water or better).

1. Turn pump on.
2. To expel any air on the feed side, flush cartridge for 5 minutes at a minimum inlet pressure of 3 psig. Outlet pressure should be 0 psig.
3. When shell side of cartridge has been completely filled with liquid, close upper permeate port completely and continue to close reject valve until a pressure of 25 psig is attained. Make sure to leave reject valve at least slightly open to prevent air entrapment. Hold at pressure for 30 minutes.
4. After holding pressure for 30 minutes, gradually open top permeate port and then open reject valve completely. Switch pump off. Open lower permeate port and allow cartridge to drain.
5. Cartridge is now sufficiently wetted to perform standard water flux test.

As a convention, flux is recorded in terms of liters per square meter of membrane surface area per hour (lmh) or gallons per square foot of membrane surface area per day (gfd). Flux in lmh is:

$$\text{Flux (lmh)} = \frac{\text{Permeate flow (ml/min)}}{\text{Cartridge area (m}^2\text{)}} \times 0.06$$

Example:

For cartridge model number UFP-10-C-5A containing 0.2 sq. m. of membrane surface area, a permeate flow rate of 200 ml/minute at a given operating pressure would calculate to a flux of 60 lmh:

$$\text{Flux} = \frac{200 \text{ ml/min}}{0.2 \text{ m}^2} \times 0.06 = 60 \text{ lmh}$$

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:

$$\text{Temperature corrected flux} = (\text{Flux})_{T2} \times \frac{T1}{T2}$$

where,
T1 = Reference temperature (e.g., 77°F)
T2 = 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 =

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

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.

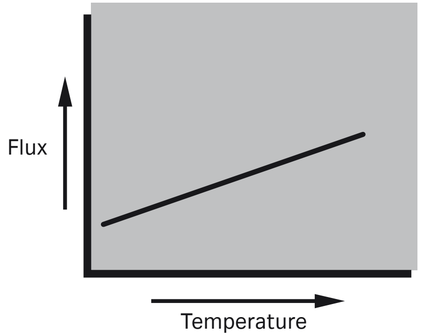
As a general rule, operation should be at the highest temperature acceptable for the membrane, given the constraints of feed stream pH and the operating pressure.

Examples:

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

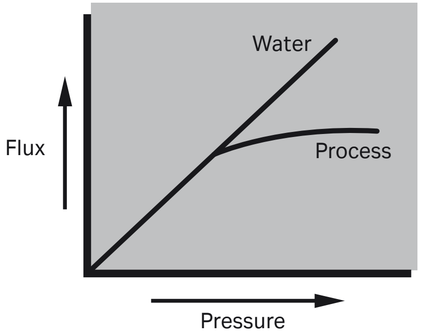
When processing at 35°C...
the clean water flux will be about 125% of the flux at 25°C.

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 page 14 for details).

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



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-and-frame 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, Cytiva offers a full range of hollow fiber membrane cartridges with nominal 1 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.

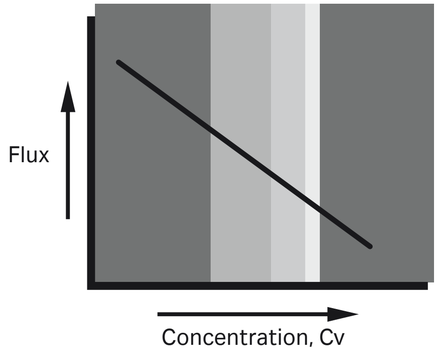
Low-fouling streams exhibit stable flux rates over time with low recirculation rates. The flux of low-fouling streams is basically concentration dependent. Thus upon feed stream dilution, the permeate rate will increase and approach the starting performance level. A feed flow rate which provides an intermediate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

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.

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.



See page 30 for feed stream flow rate chart.

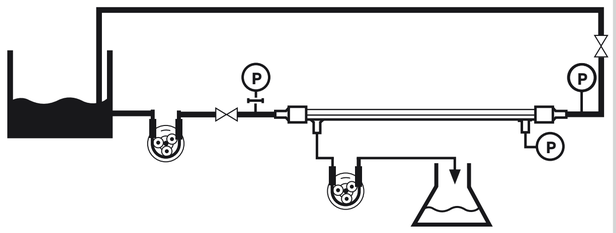
Volumetric concentration—system conversion relationship

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, %

Permeate Flow Control—When a product is being clarified through a microfiltration membrane, 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.



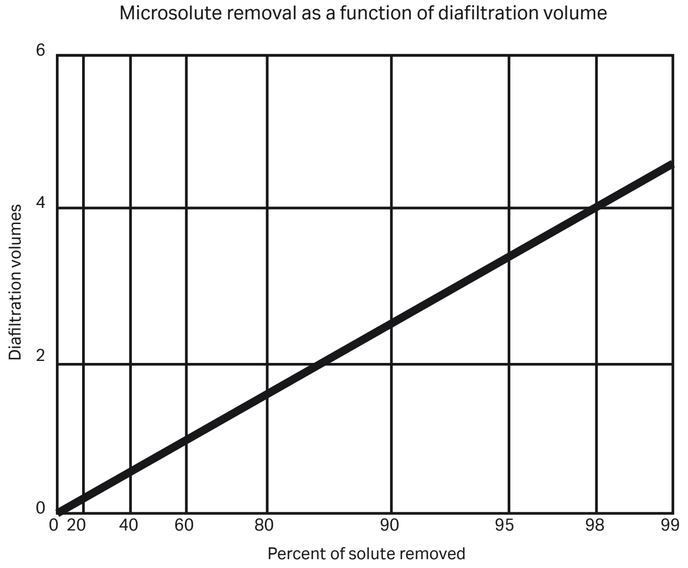
For high flux membranes, permeate flow control is an effective means of improving flow stability and increasing overall productivity.

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

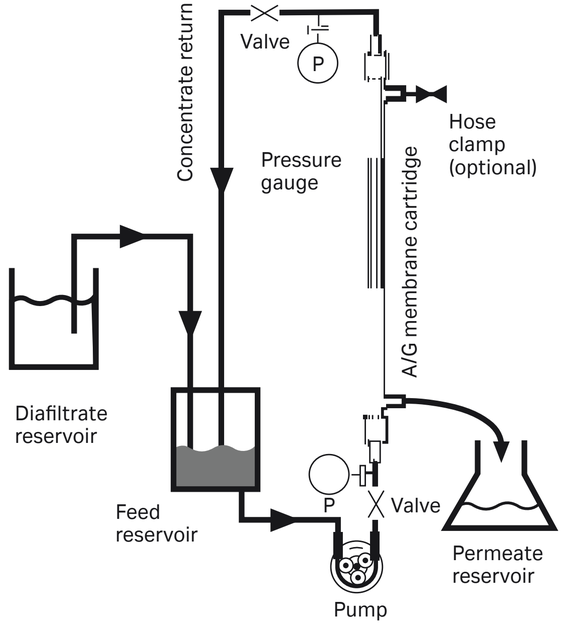
Diafiltration is a unit operation incorporating ultrafiltration membranes to efficiently remove salts or other microsolutes from a solution. The microsolutes are so easily washed through the membrane with the permeated diafiltration water that for a fully permeating species, about 3 volumes of diafiltration 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.



Flux recovery — cleaning, sanitization, storage, depyrogenation

Introduction

In almost all tangential flow membrane separations, the rate of permeate flux declines with time, even if other operating conditions and fluid properties remain constant. Flux decline which is not associated with a concentration effect (i.e., concentration polarization) can occur due to a foulant layer build-up on the membrane surface which adds resistance to permeation.

Membrane *fouling* is highly dependent on the nature of the feed stream and the extent of the concentration. Fortunately, efficient and effective membrane cleaning and sanitization steps have been developed for a wide range of applications, permitting Cytiva hollow fiber microfiltration and ultrafiltration membrane cartridges to be reused over numerous process cycles. Since these membranes are polysulfone and are supplied in polysulfone housings with epoxy potting compounds, Cytiva membrane cartridges withstand a wide range of cleaning and sanitizing chemicals and solution pH.

Basic flux recovery procedures are provided below, with a recommended protocol outlined on page 20. Optimization of the procedures in terms of chemical concentration, recirculation time, temperature and pH will typically be performed on a case-by-case basis. Even with stringent cleaning procedures and skilled operators, it may not be possible to recover permeate flux to new cartridge levels. Rather, it is important that the trend of flux recovery over time be noted and that the permeate water flux after cleaning be higher than the average initial process permeate flux. Use initial clean water flux as a benchmark for comparison.

Flux recovery—cleaning procedures

Cleaning formulations and the frequency and duration of cleaning cycles are dependent upon the stream being processed, the degree of fouling, the extent of the concentration, etc. In general, cleaning should be performed at low pressure and moderate velocity, at temperatures of 40 to 50°C. Typical cleaning formulations for processing of biologicals and for general process applications are listed in the following tables. Alternative cleaning regimes for each process are provided in the tables on pages 17, 18 and 19.

Backflushing may be beneficial for flux recovery with particulated feed streams (see page 25).

In performing these cleaning procedures, one should take into account the following considerations:

1. Flushing/rinsing/draining. **Before cleaning, flush residual feed from cartridge with clean warm (50°C) water, saline or buffer solution. Use buffer solution to prevent precipitation of solutes (e.g., proteins) during flushing. After cleaning, rinse residual cleaning agent from the cartridge.** These steps are best performed in a non-recirculating mode, such that the flush/rinse water does not re-enter the system. Rinse times/ volumes are greatly reduced by thoroughly draining both the cartridge (including the permeate area) and the system.
2. Water quality. Cleaning and flush/rinse water should contain <0.05 ppm iron, <25 ppm calcium and magnesium and no colloidal silica. Water should be free of particulate matter, oil and grease. Ideally, distilled water, ultrafiltration permeate or reverse osmosis permeate should be used.
3. Temperature. Cleaning at room temperature (i.e., 20°C) is not recommended. Preferably, cleaning should be performed at 50°C, to decrease the strength of foulant/membrane surface bonds and to improve solubility of residual feed constituents. Higher temperature cleaning (>60°C) is not recommended due to potential cleaning chemical/membrane interactions. Temperature changes in either direction should be gradual, nominally 1°C/minute.
4. Time. Nominal cleaning timing is provided with each cleaning step in the procedure tables. These times should be used as guidelines. Shorter or longer times may be required depending on the extent of the membrane fouling. In many cases, soaking the membranes overnight improves the effectiveness of the cleaning cycle. Flushing time depends on the cleaning chemical, the membrane pore size and the total void volume of the system.
5. Chlorine wash cycles. Chlorine dissipates with time and is rapidly depleted in very dirty operations. A chlorine test kit should be used to check chlorine levels and additional chlorine should be introduced as needed.
6. Safety. Caustic, acid, bleach and other cleaning chemicals should be handled with care. Operators should take appropriate precautions to prevent contact with eyes and skin.

Process	Foulants	Alternate cleaning procedures in order of preference
Mammalian cell culture	Cell debris	A. 1. Flush with clean water, buffer or saline at 50°C. 2. Circulate NaO Cl* at 50°C, pH 10-11, 1 hr. 3. Flush with clean water. B. 1. Flush with clean water, buffer or saline at 50°C. 2. Circulate 0.5N NaO H at 50°C, 1 hr. 3. Flush with clean water. C. 1. Flush with clean water, buffer or saline at 50°C. 2. Circulate 0.2% Terg-A-Zy me® at 50°C, pH 9-10, 1 hr. 3. Flush with clean water.
Bacterial cell whole broths	Proteins, cell debris, poly saccharides, lipids, antifoams	A. 1. Flush with clean water, buffer or saline at 50°C. 2. Circulate 0.5N NaO H at 50°C, 1 hr. 3. Flush with clean water. *Optional:* 4. Circulate NaO Cl* at 50°C, pH 10-11, 1 hr. 5. Flush with clean water. B. 1. Flush with clean water, buffer or saline at 50°C. 2. Circulate 0.2% Terg-A-Zy me® at 50°C, pH 9-10, 1 hr. 3. Flush with clean water. C. 1. Flush with clean water, buffer or saline at 50°C. 2. Circulate 0.5% Henkel P3-11 at 50°C, pH 7-8, 1 hr. 3. Flush with clean water.
Bacterial cell lysates	Proteins, cell debris	A. 1. Flush with clean water, buffer or saline at 50°C. 2. Circulate 0.5N NaO H at 50°C, 1 hr. 3. Flush with clean water. *Optional:* 4. Flush with H_3PO_4 at 50°C, pH 4, 1 hr. 5. Flush with clean water. B. 1. Flush with clean water, buffer or saline at 50°C. 2. Circulate NaO Cl* at 50°C, pH 10-11, 1 hr. 3. Flush with clean water. *Optional:* 4. Circulate H_3PO_4 at 50°C, pH 4, 1 hr. 5. Flush with clean water. C. 1. Flush with clean water, buffer or saline at 50°C. 2. Circulate 0.1% Tween 80® at 50°C, pH 5-8, 1 hr. 3. Flush with clean water.

*Naocl concentration varies by membrane type. Refer to table on page 29 for allowable naocl concentrations. Preferred operating conditions for flushing (prior to cleaning), cleaning and final rinse are provided on page 20.

Cleaning procedures (continued)

Process	Foulants	Alternate cleaning procedures in order of preference
Blood and serum products, enzymes, vaccines, protein products	Proteins, lipoproteins, lipids	A. 1. Flush with clean water, buffer or saline at 50°C. 2. Circulate 0.5N NaO H at 50°C, 1 hr. 3. Flush with clean water. *Optional:* 4. Circulate NaO Cl* at 50°C, pH 10-11, 1 hr. 5. Flush with clean water.
		B. 1. Flush with clean water, buffer or saline at 50°C. 2. Circulate 0.1% Tw een 80® at 50°C, pH 5-8, 1 hr. 3. Flush with clean water.
		C. 1. Flush with clean water, buffer or saline at 50°C. 2. Circulate 0.2% Terg-A-Zy me® at 50°C, pH 9-10, 1 hr. 3. Flush with clean water.
Juice and beverage clarification	Protein, pectin, colloids, tannins, poly phenolics	A. 1. Flush with clean water. 2. Circulate 0.5N NaO H at 50°C for 1 hour. 3. Flush with clean water. *Optional:* 4. Circulate NaO Cl* at 50°C, pH 10-11 for 1 hour. 5. Flush with clean water.
		B. Substitute 0.2% Terg-A-Zy me®, 50°C, pH 9-10 for NaOH.
Dairy	Protein, insoluble calcium complexes	A. 1. Flush with clean water. 2. Circulate H_3PO_4 at 50°C, pH 3.5-4 for 20 minutes. 3. Flush with clean water. 4. Circulate 0.5N NaO H at 50°C for 20 minutes. 5. Flush with clean water. 6. Circulate NaO Cl* at 50°C, pH 10-11 for 1 hour. *Monitor and maintain chlorine level.* 7. Flush with clean water.

*Naocl concentration varies by membrane type. Refer to table on page 29 for allowable naocl concentrations. Preferred operating conditions for flushing (prior to cleaning), cleaning and final rinse are provided on page 20.

Cleaning procedures (continued)

Process	Foulants	Alternate cleaning procedures in order of preference
Water treatment	Iron complexes	A. 1. Flush with clean water. 2. Circulate Citric acid at 50°C, pH 2-2.5 for 1 hour. 3. Flush with clean water. *Optional: if low water flux,* 4. Circulate a low foaming alkaline cleaner for 20 min. 5. Flush with clean water.
	Mineral scale	A. 1. Flush with clean water. 2. Circulate HNO_3 at 50°C, pH 4 for 1 hour. 3. Flush with clean water. *Optional*: 4. Repeat Step 2 and leave soaking ov ernight. 5. Flush with clean water.
		B. *Substitute H_3PO_4, 50°C, pH 4 for HNO_3.*
Edible oils	Oil, grease, colloids	A. 1. Flush with clean water. 2. Circulate 0.2% Micro® at 50°C, pH 9-10 for 1 hour. 3. Flush with clean water. *Optional:* 4. If iron fouling is suspected, wash with Citric acid, pH 2-2.5, as noted above.
		B. *Substitute alternate detergent cleaners for Micro®.* *Increase detergent concentration.*

*Naocl concentration varies by membrane type. Refer to table on page 29 for allowable naocl concentrations. Preferred operating conditions for flushing (prior to cleaning), cleaning and final rinse are provided on page 20.

Cleaning Procedures (continued)

Operation		Recommended protocol*
Flush	A.	Recirculate clean water or buffer in "total recycle"** for 10 minutes at 8,000 to 16,000 sec-1 shear rate, with 5 psig (0.3 barg) outlet pressure. Typical solution consumption is 3 to 4 times the system hold-up volume.
	B.	Drain solution.
Clean	C.	Recirculate cleaning solution in "total recycle" at 4,000 to 8,000 sec-1 shear rate for 30 to 60 minutes with 5 psig (0.3 barg) outlet pressure. Typical solution consumption is 3 to 4 times the system hold-up volume.
	D.	Drain solution.
Rinse	E.	Recirculate clean water or buffer in "total recycle" for 5 minutes at 8,000 to 16,000 sec-1 shear rate, with psig (0.3 barg) outlet pressure. Typical solution consumption is 2 times the system hold-up volume.
	F.	Drain solution.
	G.	Repeat rinse water recirculation/drain steps "E" and "F" two more times.
	H.	Rinse both retentate and permeate sides with clean water/buffer, controlling the permeate rate at 0.1 liters/minute/sq. ft. of membrane area. The retentate flow rate should be nominally 5 - 10% of the permeate flow rate.
	I.	It is preferred that the cartridge be oriented vertically and permeate be removed from the upper permeate port.
	J.	Continue to rinse for 60 minutes. [Note: 60 minutes is a nominal time frame. To conserve water/buffer, time may be reduced to 30 minutes.]

* See shear rate table on page 30.

** Total recycle = return both retentate and permeate streams to the feed reservoir.

Sanitization

For sanitization, throughly clean and rinse the membrane cartridges, then use any of the following:

1. Up to 100 ppm* sodium hypochlorite. If properly cleaned, 10 ppm should be sufficient. Circulate 30 to 60 minutes.
2. Up to 3% formalin. Circulate 30 to 60 minutes.
3. Up to 0.5 N sodium hydroxide. Circulate 30 to 60 minutes.
4. 100 to 200 ppm peracetic acid. Circulate 30 to 60 minutes.
5. Up to 70% ethanol in water.
6. Autoclave (see page 22).

*100 Ppm active naocl = household bleach diluted 250:1 with water.

Be certain that the sanitizing solution makes continuous contact with all surfaces of concern.

Storage

Flushing and rinsing protocols are listed in table to the left.

Depyrogenation

For depyrogenation, thoroughly clean, sanitize and rinse the membrane cartridges, then recirculate either of the following for 30 to 60 minutes at 30° to 50°C. Then thoroughly drain and flush with non-pyrogenic water.

1. 100 ppm sodium hypochlorite, pH 10 to 11.
2. 0.1N to 0.5 N sodium hydroxide, pH 13.

Ultrafiltration cartridges must be stored wet or reglycerized. Before storage the cartridges should be thoroughly flushed, cleaned and rinsed with clean water. For short-term storage, up to two weeks, cartridges need only be water-wet.

For storage up to 1 month, cartridges may be filled with a storage solution and sealed at all endfittings and permeate ports, or submerged in a storage bath. Acceptable storage solutions are:

1. Water with 5 to 10 ppm active chlorine (10 to 20 ppm sodium hypochlorite) Monitor levels weekly.
2. 0.1 N sodium hydroxide.
3. Up to 3% formalin.
4. 30% ethanol in water.
5. Up to 1% sodium azide.

For storage of longer than 1 month, check periodically to be certain that the membranes remain wetted. Prior to reuse it is recommended that the cartridge be rinsed with a 100 ppm sodium hypochlorite solution.

Thoroughly rinse all storage solution prior to reuse.

Microfiltration cartridges may be stored dry, after cleaning. It is advisable to clean and sanitize the microfiltration cartridges prior to reuse. If necessary, to fully wet the membranes after extended storage, expose the membranes [inside and outside] to 70% alcohol for one hour. Drain, wet with water and rinse.

Autoclaving

Essentially all Cytiva UF and MF cartridge models with housing sizes 1 through 9 are autoclavable. Larger area UF and MF cartridges may be available in an autoclavable version so please consult with a technical service representative. In all cases, cartridges which have the suffix "A" in their model number are autoclavable (e.g., CFP-2-E-3**A**, UFP-100-E-55**A**) .

Autoclaving considerations:

a. **Rinse glycerol preservative solution from new uf cartridges.** Detailed instructions are provided on page 9. The cartridge must be rinsed, soaked and rinsed again to fully remove the glycerol.

b. Do not shock cartridges while fully wet with water or while hot.

C. Never expose a warm cartridge to cold process fluids. Always allow cartridge to completely cool prior to use.

D. Loosen all clamps before autoclaving.

E. For reuse, cartridges should only be autoclaved after thorough cleaning confirmed by water flux recovery. Due to the thermal stability of polysulfone, water flux values before and after autoclaving should be similar.

It is prudent to maintain a spare cartridge on-site should cartridge life be exceeded or autoclave cycle temperature drift too high.

Be certain that autoclave temperature does not drift above 124°C.

Recommended autoclave procedure steps as depicted in graphs on page 23.
[Starting pressure = 14.7 psia; starting temperature = ambient room temperature]

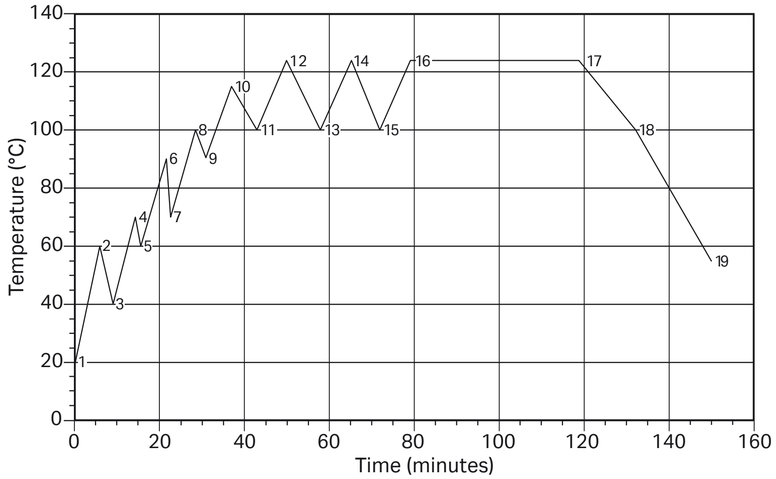
Step #	Cumulative time (Minutes)	End of step pressure (Psia)	End of step temperature (°C)	Comments
Slow warm-up				
1	0	0.7	20	Pull vacuum over 6 min. in ~ 5 in Hg increments.
2	6	2.7	60	Inroduce steam over several minutes.
3	9	1.2	40	Pull vacuum over 3 minutes.
4	14.5	4.7	70	Introduce steam over 5.5 minutes.
5	15.5	2.7	60	Pull vacuum over 1 minute.
6	21.5	10.5	90	Introduce steam over 6 minutes.
7	22.5	4.7	70	Pull vacuum over 1 minute.
8	28.5	14.7	100	Introduce steam over 6 minutes.
9	31	10.5	90	Pull vacuum over 2.5 minutes.
10	37	25	115	Introduce steam over 6 minutes.
11	43	14.7	100	Pull vacuum over 6 minutes.
Residual air reduction and temperature equalization				
12	50	33.7	124	Introduce steam over 7 minutes.
13	58	14.7	100	Pull vacuum over 8 minutes.
14	65	33.7	124	Introduce steam over 7 minutes.
15	72	14.7	100	Pull vacuum over 7 minutes.
Ramp-up and dwell at autoclave temperature				
16	79	33.7	124	Introduce steam over 7 minutes.
17	119	33.7	124	Dwell for up to 40 minutes.
Gradual cool-down				
18	132	14.7	100	Stop steam introduction, open bleed valve.
19	150	5.7	55	Slow cool down with vacuum.
20	-----			Cool cartridge completely before integrity testing. (at least 3 hours, preferably overnight).

Note: Cartridge life is a function of autoclave operating cycle, temperature, cycle time and number of cycles.

The number of autoclave cycles validated by Cytiva is guaranteed on a pro-rated basis provided an autoclave cycle which meets our approved criteria is employed. If in doubt, please submit a printout of the time/temperature/profile for our review. In practice, strict attention to proper autoclave procedures may permit 10 or more cycles per cartridge

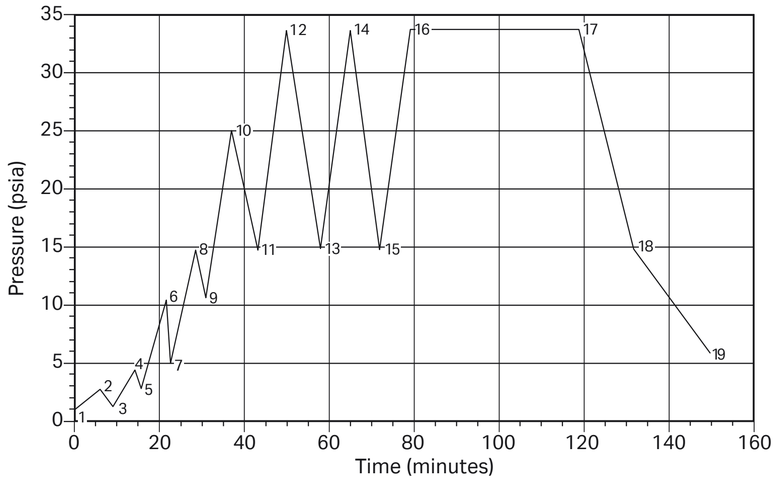
Validated autoclave cycles

Housing size	MF	UF
Size 3MA through Size 9A	5	5
Size 35A, Size 55A	5	5
Size 45A, Size 65A	2	2



Temperature as a function of time for Cytiva recommended autoclave cycle

See step by step description in table on page 22.



Pressure as a function of time for Cytiva recommended autoclave cycle

Backflushing and steam-in-place

Backflushing

Hollow fiber cartridges offer the advantage of backflushing for cleaning and flux recovery. Membranes may be backflushed with permeate at pressures of up to 10 psig provided a low velocity (about 25% of the feed rate) is used and temperature is ambient (i.e., <25°C). During backflushing, maintain a feed flow through the membrane lumen. Do not shock the membranes with pressure surges.

Alternatively, a backpressure can be created on the downstream end of the cartridge by closing off the permeate ports. Reversing the feed flow direction will apply backpressure to the other end of the cartridge.

steam-in-place

Cytiva offers a range of ultrafiltration and microfiltration cartridges which can be steam sterilized. steam-in-place cartridges slip into stainless steel housings for containment and safety.

Be certain to follow the steam-in-place protocol supplied with the cartridge.

Please call for additional information.

Membrane pore size selection

Ultrafiltration membranes are rated in terms of their nominal molecular weight cut-off (NMWC). There are no industry-wide standards for this rating, hence each manufacturer uses criteria of their own choice for assigning UF pore sizes. Cytiva offers a full range of UF pore sizes from 1,000 to 750,000 NMWC. Therefore when upgrading from another manufacturer, it may be advisable to test more than one membrane rating to determine the preferred Cytiva membrane type.

For protein concentration, the protein should be larger than the molecular weight rating of the membrane by a factor of 2 to 5X. The greater the difference (i.e., tighter the membrane pore size), the higher the protein yield.

If protein passage is desired, then an order of magnitude difference between the membrane's NMWC and the protein's size is suggested. In practice, a 500,000 NMWC UF membrane or a microfiltration membrane will be required to affect significant protein yields.

The protein shape, in addition to its molecular weight, plays a role in determining its retention by the membrane. The more globular the protein, the greater its retention. On the other hand, linear proteins may require a tighter membrane for high recoveries. Moreover, protein shape may be effected by solution pH or salinity.

Other publications available from Cytiva:

- Selection guide and price list
- UF/MF integrity test procedure guide
- UF/MF cartridge validation information

Protein binding

Cytiva polysulfone membranes are manufactured in a way that minimizes non-specific protein binding. Preliminary data suggests that our membranes exhibit up to 50% less binding than conventional membranes made from polysulfone. In process, once the relatively few available binding sites are occupied, additional protein binding is negligible. To minimize binding in instances of protein solutions, select a cartridge providing a low surface area/volume ratio. Pretreating the cartridge with either bovine serum albumin or polyethylene glycol may reduce binding even further.

Quality assurance

All Cytiva membrane products are subjected to stringent quality control standards to assure the utmost product integrity and consistency.

Cytiva quality control tests every cartridge prior to shipment. QC tests cover membrane pore size determination and integrity of the membrane as well as integrity of the complete cartridge assembly.

For ultrafiltration products, each membrane lot is checked for rejection of one or more standard markers, and clean water flux measurements are taken. Finished cartridges are pressure tested for integrity. Water flux and air diffusion measurements are recorded on a representative lot basis. Cytiva air diffusion standards are approximately three times as stringent as any other manufacturer in the industry.

For microfiltration products, each membrane cartridge is bubble point tested for pore size determination, and clean water flux measurements are taken on a representative sample of cartridges.

All Cytiva cartridges are pressure stressed prior to shipment. Ultrafiltration cartridges are stressed above their normal operating pressure limit. Microfiltration membranes are stressed to their bubble point.

The combination of clean water flux data, chemical marker rejection data and air diffusion test data clearly define both the pore size of ultrafiltration membrane fibers and the integrity of the membrane cartridge. Clean water flux data and bubble point measurements fully define microfiltration membrane pore size.

All membrane and cartridge assembly methods are thoroughly documented with SOP's and subscribe to basic GMP guidelines. Each cartridge is assigned a unique serial number to permit tracking of raw material, performance data and customer location. Certificates of analysis are available upon request.

Cytiva offers hundreds of UF and MF cartridge options with a range of lumen diameters, pore sizes, path lengths, active areas and endfitting connections. These products serve laboratory through process-scale requirements of applications as varied as cell lysate clarification and protein concentration. Hence, this operating guide can only provide the basic considerations for membrane cartridge operation. Optimization of both operating criteria and cleaning regimes are, by definition, case specific.

Key performance charts

Operating parameters

Membrane life is dependent upon feed pressure, thermal stress, pH and feed composition.

		Ultrafiltration	Microfiltration
Feed pressure	Maximum	<10°C — 75 psig 10-25°C — 65 psig 25-50°C — 50 psig 50-80°C — 50 psig	**Maximum* @ 25°C** 0.1µ — 30 psig 0.2µ — 25 psig 0.45µ — 15 psig 0.65µ — 15 psig
Transmembrane pressure	Maximum value at any point within the cartridge. Maximum transmembrane pressure = feed pressure minus permeate pressure. If permeate pressure is not measured, assume it to be o psig.	**1K-30K** <10°C — 60 psig 10-25°C — 50 psig 25-50°C — 45 psig 50-80°C — 35 psig **100K-750K** <10°C — 50 psig 10-25°C — 45 psig 25-50°C — 35 psig 50-80°C — 25 psig	**Maximum* @ 25°C** 0.1µ — 20 psig 0.2µ — 15 psig 0.45µ — 10 psig 0.65µ — 10 psig
Temperature		see above	0.1µ — up to 80°C 0.2µ — up to 80°C 0.45µ — up to 50°C 0.65µ — up to 50°C
Chlorine**	Sanitization	5 to 50 ppm	5 to 50 ppm
	Cleaning, shortterm (30 minutes, 50°C)	up to 100 ppm	up to 300 ppm
	Maximum continuous @ 20°C	100 ppm	100 ppm
pH range		2 to 13	2 to 13
Autoclavable versions	See notes on accompanying pages for conditions and number of cycles	Models with "A" as a suffix	Models with "A" as a suffix

* Operation at higher temperature decreases maximum allowable pressure. Contact Cytiva for guidelines.

psig x 0.06895 = barg

** Household bleach (e.g., Clorox®) contains ~5% (50,000 ppm) NaOCl.
Active" chlorine = one-half the concentration (ppm) of NaOCl.
Thus, 100 ppm = 250:1 dilution of bleach in water.

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 flowmeter 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 lumin ID (mm)	Sheer rate ~2000 sec-1 (liters/min)	Sheer rate ~4000 sec-1 (liters/min)	Sheer rate ~8000 sec-1 (liters/min)	Sheer rate ~16000 sec-1 (liters/min)
3M, 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, 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.

Feed stream flow rate vs. Cartridge pressure drop

Important notes to feed flow rate vs. ΔP tables

ΔP for cartridge only.

Pressure drop through piping and valves must be added. Nominal values, water, 20°C.

Temperature and viscosity of solution affect pressure drop. Figures are for laminar flow.

In laminar flow, pressure drop is a linear function of recirculation rate.

Feed flow rate vs. ΔP (water, 20°C)

housing size	Nominal lumen id (mm)	Nominal feed flow (liters/min)	Pressure drop (psig)
3M	0.5	0.25	3.3
		0.5	6.6
	1	0.6	1.9
		1.2	4.1
3X2M	0.	0.25	5.7
		0.5	11.4
4, 4M	0.5	1.2	3.2
		2.3	6.6
	1	2.5	2.0
		5	4.0
4X2M	0.	1.2	5.7
		2.3	11.4
5	0.5	4.3	2.7
		8.6	5.4
	1	8	1.6
		16	3.4
6	0.5	4.3	5.3
		8.6	10.7
	0.75	5.6	4.0
		11.2	8.0
	1	8	3.1
		16	6.3
9	0.5	10.6	5.0
		21.5	10
	0.75	18	3.7
		35	7.6
	1	24.5	2.9
		49	6.0

Feed flow rate vs. ΔP (water, 20°C) (continued)

housing size	Nominal lumen id (mm)	Nominal feed flow (liters/min)	Pressure drop (psig)
35, 35A, 35STM, 35SMO, 37	0.25	18	4.8
		36	9.7
	0.5	26	2.6
		53	5.3
	1	60	1.6
		120	3.3
55, 55A, 55R, 55STM, 55SMO	0.5	26	5.3
		53	10.6
	0.75	40	4.0
		80	8.0
	1	60	3.0
		120	9.1
75, 75R	0.5	26	9.1
		53	18.3
	1	60	5.2
		120	16
45	0.5	55	3.3
		111	6.6
65, 65MSM	0.5	55	5.2
		111	10.5
	1	122	3.0
		245	9.0
85	0.5	55	10
		111	20
	1	122	5.7
		245	17
152M	0.5	120	5.7
		240	11.5
	1	280	3
		560	9
154M	0.5	120	11
		240	22
	1	280	5.7
		560	17

This table of nominal water flux is only valid with "clean" water. Particulates, bacteria and dissolved metals in the feed water will all lower membrane cartridge productivity values. Clean water is defined as 10,000 NMWC (or tighter) UF permeate or WFI.

Nominal UF permeate flow rate with clean water feed stream (liters/min)

Pore size	Nominal fiber ID (mm)	Average TMP (psig) @25°C	3	4	5	6	8	9	35	55	75	45	65	85	152	154
1K	0.5	10	<.001	0.002	0.005	0.012	0.013	0.028	—	—	—	—	—	—	—	—
3K	0.5	10	0.004	0.020	0.08	0.16	0.18	0.40	0.37	0.95	1.7	1.0	1.7	3.7	—	—
	1	10	0.003	0.015	0.04	0.08	—	0.20	0.22	0.60	1.1	—	1.1	2.5	—	—
5K	0.5	10	0.009	0.045	0.135	0.35	—	0.8	0.9	2.3	3.4	2.0	3.4	7.4	—	—
	7.4	10	0.004	0.02	0.08	0.16	—	0.4	0.5	1.2	2.1	—	2.1	5.0	—	—
10K	0.25	10	0.030	0.10	0.35	—	0.75	—	2.0	—	—	—	—	—	—	—
	0.5	10	0.013	0.06	0.20	0.45	0.50	1.1	1.3	3.0	5.6	3.3	5.6	11.0	—	25.0
	1	10	0.006	0.03	0.11	0.25	—	0.6	0.7	1.8	3.2	—	3.2	7.6	—	—
30K	0.5	10	0.020	0.09	0.30	0.70	0.77	1.6	1.9	4.6	8.5	5.0	8.5	18.5	—	—
	1	10	0.010	0.04	0.16	0.32	—	0.8	0.9	2.4	4.2	—	4.2	9.7	—	—
50K	0.5	10	0.030	0.14	0.45	1.05	1.16	2.4	2.9	6.9	12.8	7.5	12.8	28.0	—	—
	1	10	0.015	0.06	0.24	0.48	0.60	1.2	1.4	3.5	6.4	—	6.4	14.6	—	—
100K	0.5	5	0.017	0.07	0.28	0.63	0.70	1.6	1.5	3.8	6.8	3.8	6.8	14.5	—	—
	1	5	0.015	0.04	0.14	0.28	0.36	0.7	0.8	2.1	3.7	—	3.7	8.5	—	—
300K	0.5	5	0.020	0.10	0.37	0.79	0.87	2.0	1.7	4.7	8.4	4.7	8.4	17.6	—	—
	1	5	0.010	0.05	0.21	0.42	0.54	1.0	1.2	3.0	5.5	—	5.5	12.8	—	—
500K	0.5	5	0.027	0.12	0.38	0.91	1.0	2.2	2.3	6.1	11.4	6.6	11.6	24.7	—	—
	1	5	0.020	0.08	0.22	0.53	0.68	1.6	1.7	4.0	7.0	—	8.3	17.0	18.0	38.0
750K	1	5	0.023	0.08	0.25	0.59	0.75	1.7	1.9	4.4	7.8	—	9.2	18.9	—	—

Liters/min ÷ 3.785 = US gal/min psig x 0.06895 = barg

Important notes:

1. Values at noted average TMP, 25°C.
2. Values are nominal.
3. Values to be adjusted for actual pressure.
4. Values to be adjusted for actual temperature.
5. Permeate flow rates only valid at low pressure.

$$\text{Transmembrane pressure} = (P_{inlet} + P_{outlet})/2 - P_{permeate}$$

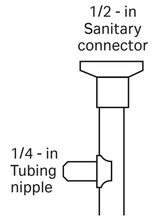
The high porosity of Cytiva microfiltration membranes results in exceptional water permeability values for these hollow fibers. Accurate permeate flow rates on a cartridge basis can only be achieved with inlet pressures of a few inches of water measured on a manometer, thus eliminating pressure gauge inaccuracies at the extremes of the scale, parasitic pressure drop and permeate back pressure from the transmembrane pressure calculation. Since it is both impractical and unnecessary to measure MF cartridge productivity with such accuracy, it is suggested initial clean water flux under a set of reproducible conditions be utilized to characterize the MF cartridge performance. In addition, a bubble point test can be performed to verify MF membrane pore size.

Minimum MF bubble point [psig (barg)]

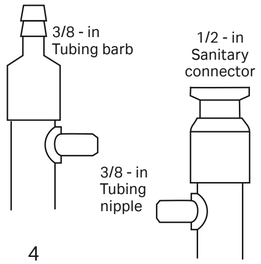
Pore size	50:50 EtOH:H2O	100% IPA
0.1µ	35 [2.4]	24 [1.6]
0.2µ	18 [1.2]	12 [0.8]
0.45µ	12 [0.8]	8 [0.5]
0.65µ	6 [0.4]	4 [0.27]

Cartridge physical properties—Xampler™ laboratory cartridges

Cytiva offers cartridge sizes to meet laboratory, pilot and production scales. Cartridges are easily manifolded together to achieve any process flow requirement. Our smaller, Xampler™ cartridges accept flexible tubing for both feed and permeate connections.



3M, 3X2M



4

Sanitary, “tri-clamp” fittings mate with adaptor fittings through the use of gaskets and clamps. Adaptor connection to a sanitary fitting is depicted below.

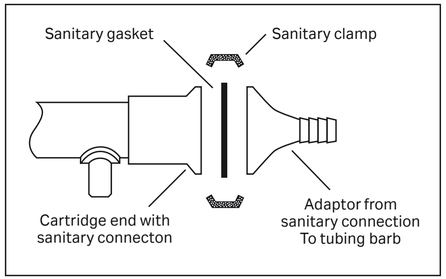
Membrane area as a function of housing and fiber internal diameter

Cartridge housing identifier	Fiber internal diameter code	Nominal fiber ID (mm)	Cartridge membrane area	
			(sq. ft.)	(sq. cm)
3M	B	0.25	0.40	370
	C	0.5	0.15	140
	D	0.75	0.13	120
	E	1	0.12	110
3X2M	C	0.5	0.31	290
	D	0.75	0.28	260
	E	1	0.24	225
4,4M	B	0.25	1.29	1,200
	C	0.5	0.70	650
	D	0.75	0.50	460
	E	1	0.45	420
4X2M	C	0.5	1.5	1,400
	E	1	0.9	850

Note: Please refer to selection guide for currently available models and their corresponding membrane areas.

Void volume and number of fibers

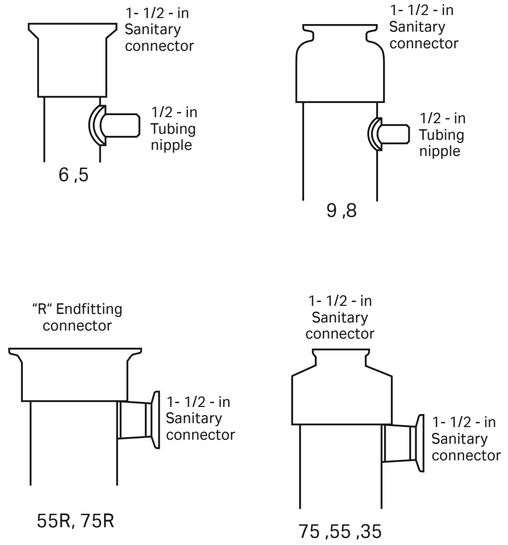
Nominal number of fibers	Nominal void volume		Cartridge housing identifier
	Lumen (ml)	Shell (ml)	
180	3	7	3M
30	2	9	
20	3	8	
13	3	5	
30	5	14	3X2M
20	6	14	
13	6	12	
600	10	42	4,4M
140	8	45	
75	10	40	
50	12	30	
140	20	75	4X2M
50	30	50	



Conversion from 1/2-in or 1-1/2-in sanitary connections to tubing barb connections.

Cartridge physical properties—pilot/process scale cartridges

Pilot and process scale cartridges are available in a full range of lumen internal diameters and membrane areas. Membranes are also offered in several housing configurations that retrofit competitive hollow fiber cartridges.



Membrane area as a function of housing and fiber internal diameter

Cartridge housing identifier	Fiber internal diameter code	Nominal fiber ID (mm)	Cartridge membrane area (sq. ft.)	Cartridge membrane area (sq. cm)
5	B	0.25	4	3,750
	C	0.5	2.1	2,000
	D	0.75	1.7	1,600
	E	1	1.3	1,200
6	C	0.5	5.2	4,800
	D	0.75	4	3,700
	E	1	3	2,800
8	B	0.25	9.7	9,000
	C	0.5	5.7	5,300
	D	0.75	4.4	4,100
	E	1	3.9	3,600
9	C	0.5	12.5	11,500
	D	0.75	10	9,300
	E	1	9	8,400
35, 35A, 35STM, 35SMO	B	0.25	29	27,000
	C	0.5	14.5	13,500
	D	0.75	10.8	10,000
	E	1	9.9	9,200
55, 55A, 55R, 55STM, 55SMO	C	0.5	35	32,500
	D	0.75	27	25,000
	E	1	23	21,000
75, 75R	C	0.5	65	60,000
	E	1	40	37,000

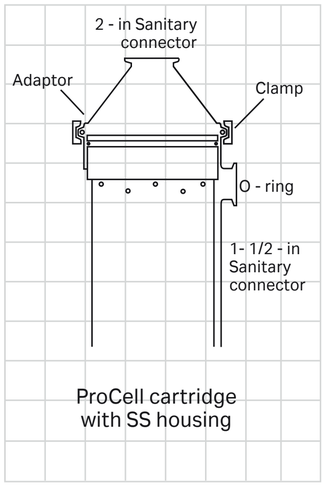
Void volume and number of fibers

Nominal number of fibers	Nominal void volume Lumen (ml)	Nominal void volume Shell (ml)	Cartridge housing identifier
remove B fiber	35	100	5
520	35	100	
300	40	85	
170	40	65	
520	75	210	6
270	75	200	
170	85	140	
remove B fiber	110	320	8
1,325	120	250	
750	120	270	
520	145	140	
1,325	225	550	9
750	225	590	
520	275	315	
remove B fiber	350	620	35, 35A, 35STM, 35SMO
3,300	350	480	
1,925	375	525	
1,250	285	385	
3,300	600	1,150	55, 55A, 55R, 55STM, 55SMO
1,925	650	1,230	
1,250	730	660	
3,300	935	2,325	75, 75R
1,275	1,170	1,165	

Cartridge physical properties—Maxcell™ and Procell™ large process scale cartridges

MaxCell™ and ProCell™ cartridges are our largest elements. With 0.5 mm ID fibers, MaxCell cartridges provide up to 140 sq. ft. (13 sq. m.) of membrane area in a single, lightweight housing. MaxCell cartridges have an integrally-bonded threaded ring at each end. A sealing gasket (o-ring) and adaptor to 2-in tri-clamp are positioned on each end and secured with a locking nut. The nut is easily tightened with a MaxCell wrench set. Permeate ports on the MaxCell cartridges are 1.5-in tri-clamp.

ProCell cartridge elements require stainless steel housings for operation. These 6-in diameter modules provide 300 sq. ft. (28 sq. m.) of membrane area with 0.5 mm ID lumen fibers.



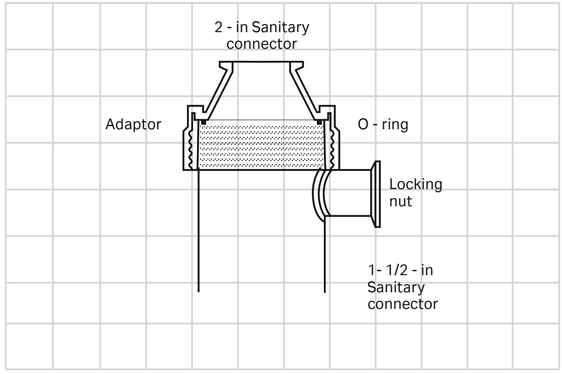
152M, 154M

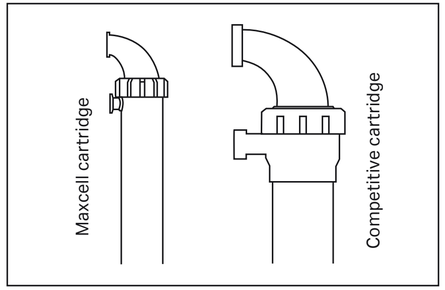
Membrane area as a function of housing and fiber internal diameter

Cartridge housing identifier	Fiber internal diameter code	Nominal fiber ID (mm)	Cartridge membrane area (sq. ft.)	Cartridge membrane area (sq. cm)
45	C	0.5	37	3.5
	D	0.75	28.5	2.65
	E	1	27	2.5
45MSM	E	1	25	2.3
65	C	0.5	66	6.1
	E	1	47	4.4
65MSM	C	0.5	60	5.6
	E	1	45	4.2
85	C	0.5	140	13
	E	1	97	9
152M	C	0.5	140	13
	E	1	102	9.5
154M	C	0.5	300	28
	E	1	215	20

Void volume and number of fibers

Nominal number of fibers	Nominal void volume Lumen (ml)	Nominal void volume Shell (ml)	Cartridge housing identifier
6,700	620	1,250	45
3,700	645	1,400	
2,600	800	675	
2,400	750	500	45MSM
6,700	1,000	2,200	65
2,600	1,280	1,170	
6,700	950	2,000	65MSM
2,400	1,200	875	
6,700	1,900	4,550	85
2,600	2,470	2,440	
13,800	2,200	3,300	152M
5,825	2,900	950	
13,800	4,200	7,000	154M
5,825	5,500	2,000	





MaxCell cartridges can easily retrofit competitive 5-inch diameter cartridges.

Key performance charts for 2 and 3 mm id tubules

Cytiva manufactures both 2 and 3 mm ID tubules to complement its line of hollow fiber membranes. These polysulfone tubules are available in ultrafiltration pore sizes of 30,000 NMWC, 100,000 NMWC and 500,000 NMWC. A 0.1 micron microfiltration membrane is provided in the 2 mm tubule diameter. These products are typically used in food, beverage and industrial applications; hence, their key performance charts are segregated from the general bio/pharm information provided elsewhere in this operating guide.

		Ultrafiltration	Microfiltration
Feed pressure	Maximum	<10°C — 45 psig 10-25°C — 40 psig 25-50°C — 35 psig 50-80°C — 25 psig	**Maximum* @ 25°C** 0.1µ — 35 psig
Transmembrane pressure	Maximum value at any point within the cartridge. Maximum transmembrane pressure = Feed pressure minus permeate pressure. If permeate pressure is not measured, assume it to be 0 psig.	<10°C — 35 psig 10-25°C — 30 psig 25-50°C — 25 psig 50-80°C — 20 psig	**Maximum* @ 25°C** 0.1µ — 25 psig
Temperature		see above	up to 80°C
Chlorine**	Sanitization	5 to 50 ppm	5 to 50 ppm
	Cleaning, shortterm (30 minutes, 50°C)	up to 100 ppm	up to 300 ppm
	Maximum continuous @ 20°C	100 ppm	100 ppm
pH Range		2 to 13	2 to 13

Housing size	Nominal tubule ID (mm)	Nominal feed flow (liters/min)	Pressure drop (psig)	
55, 55R	2	150	4.2	T
		300		
75, 75R	2	150	6.8	T
	3	250	8.7	T
85	2	265	7.4	T
	3	510	9.5	T
154	2	600	8	T

Pressure drop for cartridge only.
Pressure drop through piping and valves must be added.
Nominal values, water, 20°C.
Solution temperature and viscosity affect pressure drop.
T = Figures are for turbulent flow.

Membrane area as a function of housing and tubule internal diameter

Cartridge housing identifier	Tubule internal diameter code	Nominal tubule ID (mm)	Cartridge membrane area	
			(sq. ft.)	(sq. cm)
4X2TC	H	2	0.6	0.05
	K	3	0.4	0.04
6	H	2	2.4	0.22
	K	3	1.8	0.17
9	H	2	5	0.46
	K	3	4.7	0.43
10	H	2	10.2	0.95
	K	3	9.1	0.85
55, 55R	H	2	14	1.3
	K	3	10.6	1
75, 75R	H	2	27	2.5
	K	3	21	2
85	H	2	60	5.6
	K	3	45	4.2
154M	H	2	112	10.4

Void volume and number of tubules

Nominal number of tubules	Nominal void volume		Cartridge housing identifier
	Lumen (ml)	Shell (ml)	
51	35	70	4X2TC
8	40	65	
65	125	140	6
33	145	120	
150	325	500	9
90	415	360	
150	600	785	10
90	700	625	
390	900	1,050	55, 55R
205	1,020	850	
390	1,465	1,810	75, 75R
205	1,670	1,510	
760	3,300	4,300	85
400	3,400	3,600	
1,500	5,950	7,350	154M

Chemical resistance

In general, Cytiva polysulfone membrane cartridges are resistant to aqueous mineral acids, alkalis and salt solutions. They are also resistant to most alcohols and aliphatic hydrocarbons, as well as detergents and hydrocarbon oils. Polar organic solvents such as ketones, chlorinated hydrocarbons and aromatic hydrocarbons should be avoided. Conservative guidelines are presented below.

These guidelines are based on normal operating conditions and ambient temperature (≤25°C)—adjustments in pressure and/or temperature or presence of other components in the feed solution may alter these recommendations. When at or near the acceptable upper concentration limit for solvents, maximum pressures should be reduced by 25%. Questions pertaining to higher chemical concentrations or membrane resistance to chemicals not listed should be addressed to our customer service personnel.

Cytiva polysulfone membrane cartridge chemical compatability

Reagent	Usage
Acetic acid (<5%)	Acceptable
Acetic acid (>5%)	Short term only
Acetic anhydride	Not recommended
Acetone	Not recommended
Acetonitrile (≤10%)	Short term only
Aliphatic esters	Not recommended
Amines	Not recommended
Ammonium chloride (<1%)	Acceptable
Ammonium hydroxide (<5%)	Acceptable
Benzene	Not recommended
Butanol (<1%)	Acceptable
Butyl acetate	Not recommended
Butyl cellosolve	Not recommended
Calcium chloride	Acceptable
Chloroform	Not recommended
Citric acid (≤1%)	Acceptable

Reagent	Usage
Cyclohexanone	Not recommended
Dichlorobenzene	Not recommended
Diethanolamine (≤5%)	Acceptable
Dimethyl acetamide	Not recommended
Dimethylformamide	Not recommended
Dimethyl sulfoxide	Not recommended
Disodium salt of EDTA (≤10%)	Acceptable
Ethanol (≤10%)*	Acceptable
Ethyl acetate	Not recommended
Formaldehyde (≤1%)	Acceptable
Formic acid (≤1%)	Acceptable
Furfural	Not recommended
Glutaldehyde (≤0.5%)	Acceptable
Glycerine (≤2%)	Acceptable
Guanidine HCL (6 M)	Acceptable
Hydrochloric acid (≤0.01 N)	Acceptable

Reagent	Usage
Hydrogen peroxide (≤1%)	Short term only
Isopropyl acetate	Not recommended
Isopropyl alcohol (≤10%)*	Acceptable
Kerosene	Not recommended
Lactic acid (≤5%)	Acceptable
Mercaptoethanol (≤0.1M)	Acceptable
Methyl alcohol (≤10%)*	Acceptable
Methylene chloride	Not recommended
Methyl ethyl ketone	Not recommended
N-Methyl pyrolidone	Not recommended
Nitric acid (≤1%)	Short term only
Nitrobenzene	Not recommended
Oleic acid (≤5%)	Short term only
Oxalic acid (≤1%)	Acceptable
Phenols (<1%)	Acceptable
Phosphoric acid (≤0.1N)	Short term only

Reagent	Usage
Sodium azide (≤1%)	Acceptable
Sodium chloride	Acceptable
Sodium dodecyl sulfate (≤0.1%)	Acceptable
Sodium hydroxide (≤1 N)	Acceptable
Sodium hypochlorite (≤300 ppm)	Acceptable
Sodium hypochlorite (>300 ppm)	Short term only
Sodium nitrate (≤1%)	Acceptable
Sulfuric acid (≤1%)	Acceptable
Terg-a-zyme® (≤1%)	Acceptable
Toluene	Not recommended
Tris buffer (pH 8.2,1M)	Acceptable
Triton X-100 (<200 ppm)	Acceptable
Urea (≤4M)	Acceptable
Xylene	Not recommended

Chemicals noted as “short term only” are typically acceptable for membrane cleaning.

*Higher alcohol concentrations acceptable depending on operating conditions. 100% alcohol acceptable for non-pressurized exposure.

Note: MidGee™ cross flow filters have the same polysulfone membranes as our larger cartridges. However, the housing materials are different. Please refer to the Midgee operating guide.

cytiva.com

For local office contact information, visit cytiva.com/contact

CY28744-18Jul22-HB

cytiva