Manual | Ultrafiltration

DuPont™ IntegraTec™ Modules

Process and Design Manual

Version 6

September 2025

Water Solutions

Table of Contents

List of Figures

List of Tables

1 Legal Notice

1.1 Product

This manual applies to DuPont™ IntegraTec™ Modules and rack, parts and components for installation, assembly and disassembly.

Duplication and archiving in any form whatsoever – including of excerpts – is only permitted with the written consent of the manufacturer.

All brand and company names in these process and design guidelines are registered trademarks of the corresponding companies.

1.2 Change Policy

The manufacturer reserves the right to change this process and design guidelines or any part thereof at any time in the interest of continuous product improvement.

The company/party responsible for process and design of the system described in this manual should obtain the current DuPont™ IntegraTec™ Modules Process & Design Guidelines at regular intervals:

- Download at: https://www.dupont.com/brands/integratec-ultrafiltration.html

2 About these Instructions

NOTE	
	READ THE INSTRUCTIONS! Read this document to plan your system. The process and design guidelines described in this document are only to be viewed as recommendations for your system. The system integrator and the operator are responsible for compliance with applicable legal and local regulations for environment, health and safety (EHS).

2.1 Objective of these Instructions

This document contains a detailed description of all process and design guidelines of the DuPont™ IntegraTec™ IP Modules for Ultrafiltration Rack and Open Platform Modules.

This document contains instructions and rules for the correct and safe operation of the system.

Warranty Policy

NOTE	
	ADHERENCE TO ALL INSTRUCTIONS! Full and proper compliance with the instructions in these process and design guidelines is a prerequisite for making a claim under the warranty. Any translations of this document into languages other than English provided to you by DuPont are not official translations and are intended solely as a convenience for non-English reading recipients. The only DuPont-approved and valid version of this document is the most current English version provided by DuPont at the time of sale. In the event of making a warranty claim, the customer agrees to automatically provide DuPont with a complete set of documentation. Please contact DuPont if you wish to deviate from any of the guidelines or specifications provided in this document and request written approval in advance. Otherwise, you risk invalidating any warranty claims that you may make in the future.

2.2 Target Groups

Qualified Persons

- Project and planning engineers/technicians
- Programmers
- Commissioning engineers/technicians
- Design engineers

2.3 Symbols in this Process and Design Guidelines

2.3.1 Symbols in this Manual

The following symbols are used in this manual:

SYMBOL	*DESCRIPTION (EXAMPLES)*
	**IMPORTANT NOTE!** Failure to follow the instructions in this note may lead to problems with the product.
	**INFORMATION!** Following this information will make it easier to assemble the PES-UF Modules.
	**CROSS REFERENCE!** Detailed information on this topic can be found in other documentation.

2.3.2 Notes on Instructions and Rules

To ensure correct, safe and fault-free operation of the system, the document highlights instructions and rules in the following manner:

NOTE	
	**ATTENTION!** Observe the following guidelines!

3 Introduction to Ultrafiltration

3.1 Introduction

A separation spectrum diagram is shown on Figure 1. It depicts the most common technologies applied for the removal of diverse contaminants or substances present in a feed stream of water supplies. While Electrodeionization (EDI), Ion Exchange (IER), Reverse Osmosis (RO) and Nanofiltration (NF) target the removal of solutes from the feed stream, Ultrafiltration (UF), Fine Particle Filtration (FPF) and Microfiltration (MF) separate fine particles, suspended solids, colloidal matter, microorganisms (e.g., cryptosporidium or giardia cysts) and low molecular weight species.

UF is a pressure-driven process that achieves separation through sieving (i.e., size exclusion) depending on its pore size and molecular weight cut-off (MWCO) expressed in kilodaltons (kDa). The pore size is the nominal diameter of the micropores in the membrane expressed in microns (µm). The MWCO is the molecular mass or weight of a solute that is rejected greater than 90 percent. UF membranes can be as fine as 3 kDa or as coarse as 150 kDa. Typically, coarse UF membranes in the range of 80 – 150 kDa (equivalent to a pore size of 0.02 – 0.03 µm) are used in water treatment applications as they have a good balance between rejection and permeability. This pore size can provide a barrier to viruses often found in water sources.

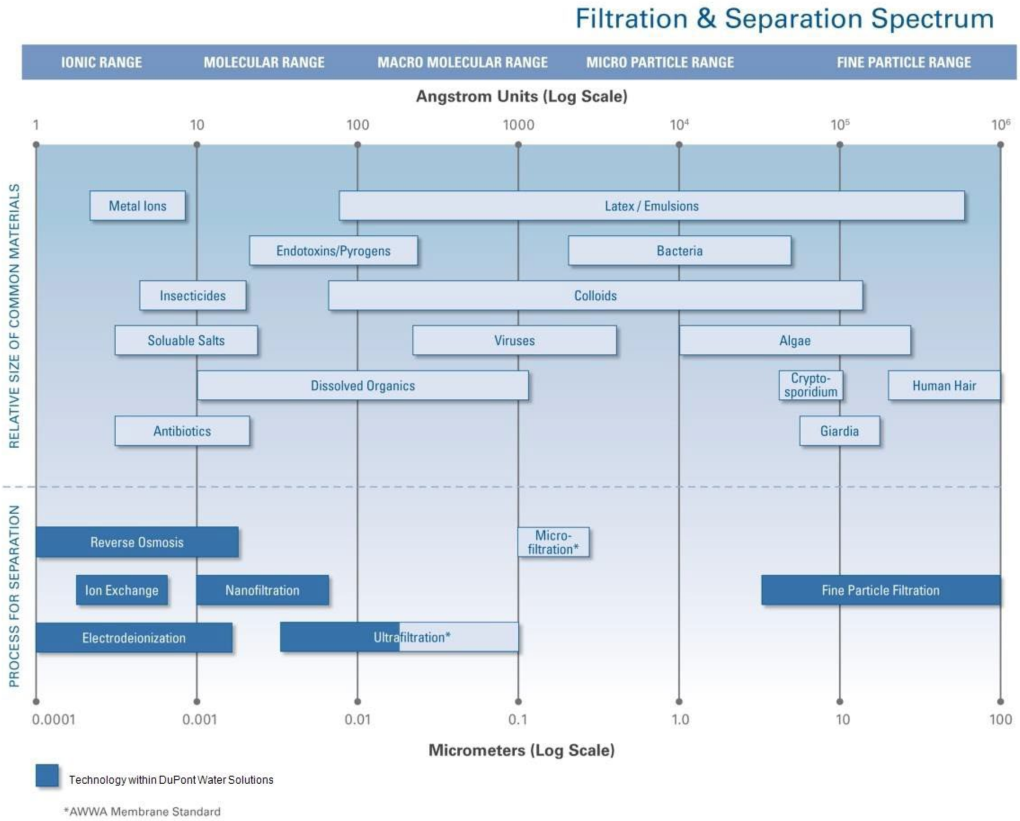

Figure 1: Separation Filtration Spectrum

3.2 Ultrafiltration Applications

The increasingly stringent requirements for quality standards of water supplies have facilitated the widespread application of UF in the industrial and municipal markets, offering an excellent choice among conventional filtration processes (e.g., media filtration, or coagulation-flocculation-sedimentation). Compared to Microfiltration, UF can offer higher virus removal capability. By physically removing pathogens, UF membrane filtration can also significantly reduce downstream chemical addition (e.g., chlorine).

UF is widely used as well in an integrated membrane treatment scheme as pretreatment to RO or NF to reduce membrane fouling potential. As RO membranes are widely accepted for the removal of ionic impurities from water bodies, the water sources that are being used to feed RO systems demand good pretreatment. RO membrane manufacturers recommend a Silt Density Index (SDI) of 3 or less to help achieve improved performance, which UF membranes fall well under.

The main applications for UF in the water and wastewater field are seawater RO pretreatment, seawater NF pretreatment (e.g., water injection in the Oil & Gas field), groundwater or surface water treatment (e.g., to produce drinking water, as a stand-alone technology), water treatment for industrial use and wastewater treatment (either municipal or industrial, e.g., for reuse).

3.3 Ultrafiltration Advantages

There are several reasons to consider Ultrafiltration as an excellent choice for pretreatment as opposed to conventional technologies:

1. Ability to cope with difficult and variable waters: Ultrafiltration membranes are a physical barrier against most particles, suspended matter, colloids, bacteria and even viruses, that can produce an excellent water quality independently of variations in the influent water quality.
2. Improved and more consistent product quality: Due to their fine pores, ultrafiltration membranes can provide a very high quality filtrate, with typical ultrafiltrate turbidity less than 0.1 NTU (independent of the raw water turbidity), SDI less than 3%/min and 6-log or more removal of pathogens such as ***Cryptosporidium-i1- and -i-*** ***Giardia*** cysts.
3. Smaller plant footprint and less weight: UF pretreatment systems require a smaller footprint (up to 50% lower) and weight than media filtration systems. This can lead to a reduced cost of land acquisition, building design, and transport.
4. Module and Rack Integrity Testing can be done easily on line to detect potential leakages without significant plant downtime.
5. Membrane modules can be individually isolated for repair, maintenance or replacement without compromising the plant output.
6. Ease of design and operation: Despite requiring more focus on sustained permeability and productivity, ultrafiltration systems offer much more stable water quality than a multimedia filtration system, without the need to monitor filter ripening time or breakthrough, or the need of ensuring appropriate layering of multimedia after backwash. Therefore process design is less complicated and control is more automated than with conventional pretreatment.
7. Lower environmental impact: Conventional systems typically require chemical pretreatment such as coagulation and pH adjustment for the removal of silt and fine particles, but UF can remove these contaminants just by size exclusion due to the small size of the membrane pores. This can lead to lower chemical consumption and lesser environmental concerns for wastewater disposal.

Lower RO stage cost: The potential for lower downstream cost, based on improved and more consistent water quality facilitated by the UF system, is a key aspect. UF as pretreatment also allows higher design flux in the RO stage, as well as lower requirements for membrane cleaning and ultimately lower replacement rates, by facilitating a RO feed water with lower fouling tendency. In addition, cartridge filters use can be significantly reduced or eliminated (especially when there is no break tank in between UF and RO).

3.4 Ultrafiltration Operating Modes

Ultrafiltration systems in water treatment applications often work in the so called Dead-End (or Direct Filtration) mode as opposed to the Concentrate Recirculation (or Cross-Flow) or Bleed Operation modes, which will be described below. As contaminants build on the membrane surface the membrane permeability drops and the transmembrane pressure (TMP) increases until the operation would become inefficient and the membrane would need to be restored. In order to minimize contaminant build-up and maintain stable plant performance, these strategies include Air Scour, Gravity Drain, Backwash, Forward Flush or chemical based aids such as Chemically Enhanced Backwash (CEB). All of them are described in this document.

3.4.1 Dead-End Mode

In the Dead-End operation mode (also known as "Deposition Mode"), all the feed volume entering the UF elements passes through the membrane (there is no reject stream) and is collected on the filtrate side, so there is 100% recovery of the water. The contaminants that are not small enough to pass through the membrane are either trapped on the membrane surface or stuck inside the pore channels, leading to an increase in the TMP and a decline of permeability. At some point the system is taken off-line and the membranes are cleaned hydraulic or chemically.

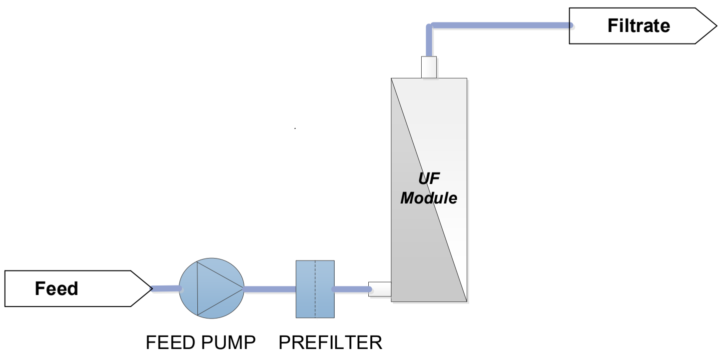

Figure 2: Dead-End Operating Mode

The Dead-End mode uses less energy and the plant design and operation is simpler as opposed to the modes involving tangential flow (See Figure 2). For this reason it has become the main operating choice in most ultrafiltration systems. The higher fouling rate associated to this operating mode is counteracted with more frequent backwashes and chemical cleanings.

3.4.2 Cross-Flow and Bleed Mode

These operating modes are used on high fouling waters to avoid excessive build-up of contaminants on the membrane surface. The shear force generated on the membrane surface by the tangential flow (parallel to the membrane) reduces the fouling rate as it continuously removes the contaminants away from the module.

In the Concentrate Recirculation mode (or Cross-Flow), the concentrate flow exceeds the filtrate flow passing through the membrane (typically in a ratio of 5:1 or higher). The concentrate stream is then typically recycled back to the feed tank or to the recirculation pump suction side (see Figure 3). This allows increasing the flow velocity through the feed channels and therefore achieving a shear force effect.

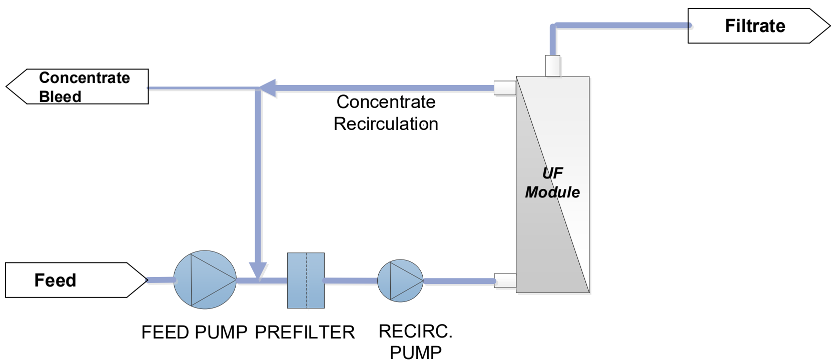

Figure 3: Concentrate Recirculation Operating Mode

The main disadvantages of the Cross-Flow operation mode are the higher energy consumption due to the high flows used to create enough flow velocity, the cost of the recirculation pump (or a larger feed pump) and the greater complexity of the system design.

In the Bleed Operation (see Figure 4), half way between Dead-End and Cross-Flow mode, most of the feed water will pass through the membrane while the rest will get out of the UF element directly through the concentrate side (typically 5 – 15% of the feed flow). This concentrate stream will carry part of the contaminants out of the elements and is normally sent to drain. This operating mode is typically achieved by just partially opening the concentrate valve of the UF Rack during the filtration cycle, and can be a good alternative to dead-end operation to better control the fouling rate during episodes of worsened feed water quality.

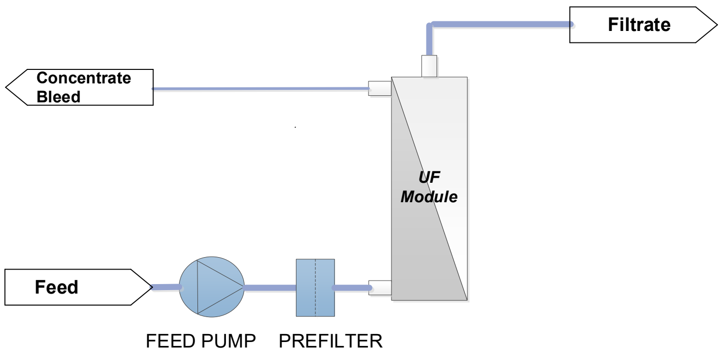

Figure 4: Concentrate Bleed Operating Mode

3.5 Ultrafiltration Module and System Configuration

PVDF-UF products use hollow fibers, unlike RO/NF elements which are dominated by spiral wound configuration. Hollow fiber PVDF-UF modules usually consist of several thousand fibers bundled together. The inner diameter of the hollow fibers is typically less than 1 mm. The main advantage of hollow fibers is that they can be backwashed.

Depending on the type of driving filtration force, the UF modules can be categorized as pressurized (belong to P Series) or vacuum driven (belong to I Series). In the pressurized form, the membranes are placed inside pressure vessels (with vertical or horizontal orientation), and the UF modules are grouped in parallel to form racks or trains. Typical operating pressure of pressurized PVDF-UF systems is up to 2.5 bar (35 psi). The vertical orientation allows easier drain, the use of air as an aid to increase cleaning efficiency and the elimination of extra vessels or housings

Vacuum driven UF modules are typically submerged in a feed tank with no membrane housing, and can only operate at low suction pressures, typically below 0.8 bar (vacuum pressure). Due to this limitation in the maximum pressure that can be applied, they must operate at a lower flux than pressurized systems and are more sensitive to water temperature fluctuations. Also the module installation, cleaning, fiber repair, isolation or maintenance are more laborious in submerged systems.

3.6 Ultrafiltration Membrane Features

3.6.1 Materials

The most common materials for UF membranes for water treatment applications are organic polymers, such as Polyvinylidene Difluoride (PVDF), Polysulfone (PS), Polyethersulfone (PES), Polypropylene (PP) or Cellulose Acetate (CA). PVDF and PES are the most common product in the market.

The polymer desired properties are good permeability, hydrophilicity (easier to wet and more resistant to adsorptive fouling), narrow pore size distribution, good tolerance to pH, temperature and chemicals, robustness (strength and elongation), and long life.

PVDF is a very flexible and robust material (i.e., good strength and elongation), with excellent break resistance and superior tolerance to chlorine (significantly higher than other materials such as PS/PES or PP), which is a key advantage in water treatment applications.

3.6.2 Flow Pattern

In a hollow fiber the flow pattern can be from “inside to outside” or from “outside to inside” and is manufacturer specific. When operated in an inside-out mode, the feed water enters the fiber lumen and passes through the fiber wall to produce filtrate in the outer side. When operated in the outside-in mode, on the contrary, the feed water enters the module, passes through the fibers from the outer wall and the filtrate is collected in the inside lumen.

In Outside-In configuration there is no risk of fiber plugging, so the UF modules can cope better with challenging feed water conditions and are more suitable for treatment of higher fouling waters. In addition, it allows the use of air for fouling control and needs lower volume for backwash compared to Inside-Out fibers. Typically a flexible and robust material such as PVDF is used in Outside-In hollow fibers.

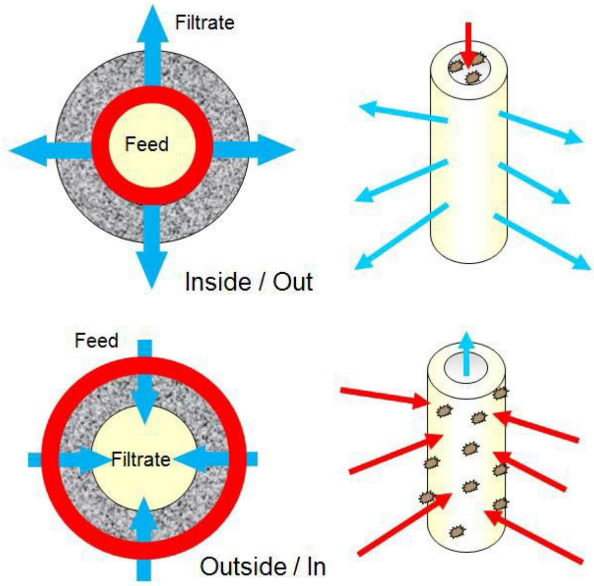

Figure 5: Inside/Out vs. Outside/In Operation

3.7 Ultrafiltration Filtrate Quality

DuPont™ IntegraTec™ ultrafiltration modules are very suitable for removing turbidity with typical filtrate values of < 0.1 NTU, SDI < 3, cyst-sized pathogens removal of more than 6-log and virus removal higher than 2.5-log. The absolute barrier achieved with UF membranes and the uniformity of the pore size, facilitates a consistent filtrate quality regardless of fluctuations in the feed water characteristics, unless there is an integrity problem in the fibers or modules. The main feature and objective of UF systems is to consistently provide low turbidity filtrate.

However, dissolved substances are not removed by UF membranes at a high extent (removal of e.g., Dissolved Organic Carbon is typically < 15%). Removing these substances by UF requires them to be transformed first into particulate form, e.g., through oxidation, pre-coagulation or adsorption.

Removal of metals such as Iron (Fe) and Manganese (Mn) is dependent on the oxidation state of these species. UF can remove Fe and Mn if they are in precipitate form (not in dissolved form). Fe and Mn can be oxidized upstream of the UF with aeration (more effective for Fe) or chemical oxidizing agents such as chlorine, permanganate, ozone or chlorine dioxide. Higher pH favors precipitation.

4 DuPont™ IntegraTec™ Modules

This section includes the description of IntegraTec™ IP Modules, ultrafiltration rack and IntegraTec™ modules for Open Platform.

4.1 Module Features

IntegraTec™ Modules are made with high-strength, hollow fiber membranes with features and benefits including:

- 0.03 µm nominal pore diameter for removal of waterborne pathogens, bacteria, viruses, and fine particulate matter including colloids.
- PVDF fibers free of macro voids for high mechanical strength with excellent chemical resistance offering long membrane life and reliable operation.
- Hydrophilic PVDF fibers for easy cleaning and wettability that help maintain long term performance.
- Outside-In flow configuration for high tolerance to feed solids and the use of air scour cleaning.
- UF module housings eliminate the need for pressure vessels

The outside-in flow configuration allows the use of highly effective air scour cleaning which enhances particle removal and improves recovery. A dead-end flow format achieves higher recovery and energy savings. The module housing design eliminates the need for separate pressure vessels while the vertical orientation allows gravity draining and facilitates the removal of air from cleaning and integrity testing processes.

The fibers are strong because of a combination of the PVDF polymer, dense substructure and selective active layer formed on the feed side of the fiber. The PVDF membranes offer high chemical resistance, coping with NaOCl concentrations up to 2000 mg/L, and are tolerant to temperatures of 40°C. The hydrophilicity of the PVDF fibers is increased through a proprietary manufacturing process.

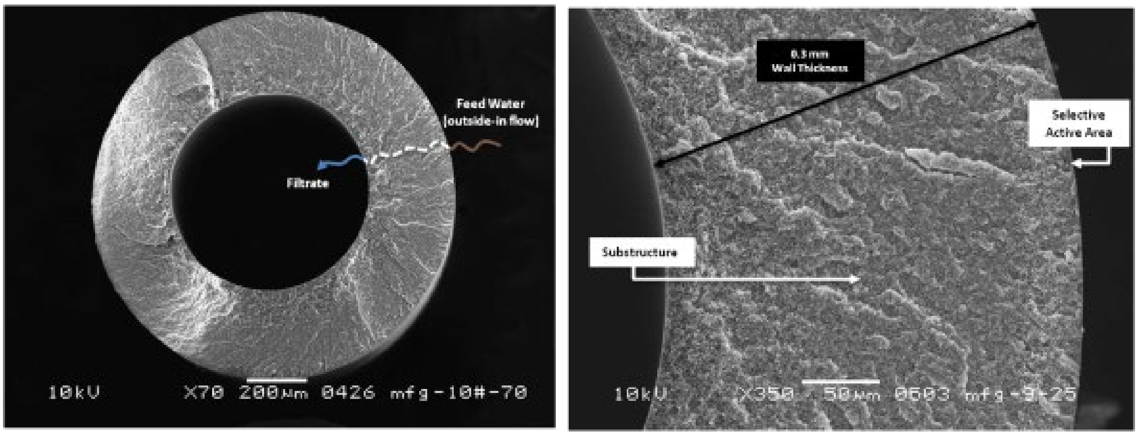

Figure 6: Wall Cross Section of a Hollow Fiber Membrane

4.2 Pre-startup Conditioning Rinsing Instructions for Potable Use Applications

The DuPont™ IntegraTec™ Ultrafiltration Modules should be rinsed prior to startup to remove preservative fluid shipped in the modules. Flushing should be performed until no foam is observed in the wash water. Depending on the treatment application, additional rinsing or disposal of the filtrate may be required.

NSF / ANSI Standard 61 certified modules require the following conditioning rinse prior to producing potable water:

1. Rinse the modules at a feed rate of 40 LMH minimum for a period of 4 hours.
2. Achieve a minimum total rinse volume of 160 L/(m²h) using the feed water available.
3. The concentrate bleed rate should be set from between 0 – 20% with the balance being filtrate.
4. During the rinse cycle, perform standard cleaning protocols as per DuPont's recommendations which are specifically designed to consider the feed water quality available.

4.3 Product Portfolio

Figure 7: DuPont™ IntegraTec™ Modules for Open Platform

Figure 8: DuPont™ IntegraTec™ IP Modules

Figure 9: IntegraTec™ modules with adaptive end caps

5 PVDF Out-In Operating Modes

The basic operating conditions for the DuPont™ IntegraTec™ Ultrafiltration Modules are shown in the table below. Operating
parameters for the cleaning steps are provided in Section 8.

Table 1: Ultrafiltration Modules Operating Conditions

Operating Conditions	SI	US
Maximum Inlet Feed Pressure	6.25 bar @ 20°C	90.65 psi @ 68°F
Operating TMP (Maximum)	2.1 bar	30.50 psi
Backwash TMP (Maximum)	2.5 bar	36.25 psi
Operating Air Scour Flow (Recommended)	12 Nm³/h/module (7 Nm³/h/module for SFP/D-2660)	7 scfm/module (4 scfm/h/module for SFP/D-2660)
Air Scour Pressure	0.35 – 2.5 bar	5.0 – 36.25 psi
Filtrate Flux @25°C	40 – 110 L/(m²h)	24 – 65 gfd
Temperature	1 – 40°C	34 – 104°F
Operating pH Range	2 - 11	
NaOCl, Cleaning Maximum	2,000 mg/L	

5.1 Filtration

Ultrafiltration systems are most of the time in Filtration mode while in operation. The feed water is pumped through the membrane and is converted to filtrate. Typically, in Filtration mode, all feed is converted to filtrate, in what is referred as dead-end filtration (as opposed to cross-flow filtration where a fraction of the feed leaves the system as reject). Filtration cycles typically range from 20 – 90 minutes, depending on the feed water source and quality. Figure 5 shows a diagram of the Filtration step in Ultrafiltration Modules.

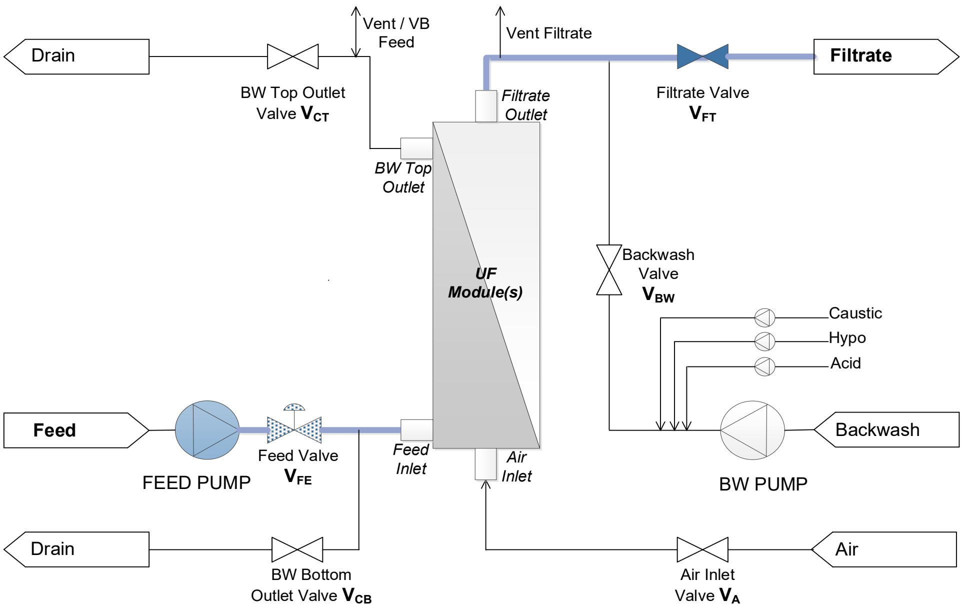

Figure 10: Filtration

Ultrafiltration systems are typically designed to operate at constant flowrate. As the solids build on the membrane surface, the transmembrane pressure (TMP) increases and eventually the foulants must be removed through a Backwash sequence. The Backwash sequence is generally initiated based on time. Alternatively, it can be initiated based on volume of filtrate or TMP set point (the latter is more appropriate for highly variable feed water quality). The Backwash sequence includes Air Scour, Gravity Drain, Backwash through the module top outlet, Backwash through the module bottom outlet and a final Forward Flush or rinse.

5.2 Air Scour

The Air Scour step is used to loosen particulates deposited on the outside of the membrane surface. Oil-Free air is introduced through the bottom of the module creating a stream of ascending bubbles which help to scour material off the membrane. Displaced water volume is allowed to discharge through the top port of the module for disposal, as shown in Figure 11. After a minimum of 20 – 30 seconds of continuous Air Scour, the module is drained by gravity.

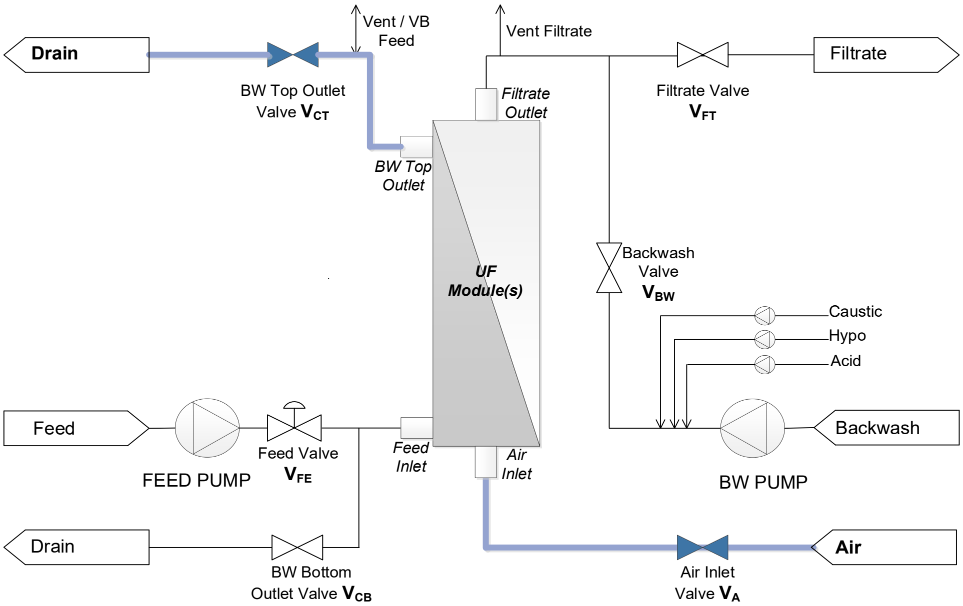

Figure 11: Air Scour

5.3 Gravity Drain

Once the Air Scour step is finished, the module must be drained by gravity in order to flush out of the system the material dislodged from the membrane surface by the preceding air scour step, as shown in Figure 12. The duration of this step will depend on the system volume and piping layout, but it is typically set to 30 – 60 seconds. If gravity drain is not possible due to the system configuration, or it takes too long, it can be substituted by a forced flush through the bottom outlet of the module using the backwash pump, however this will consume more water and energy.

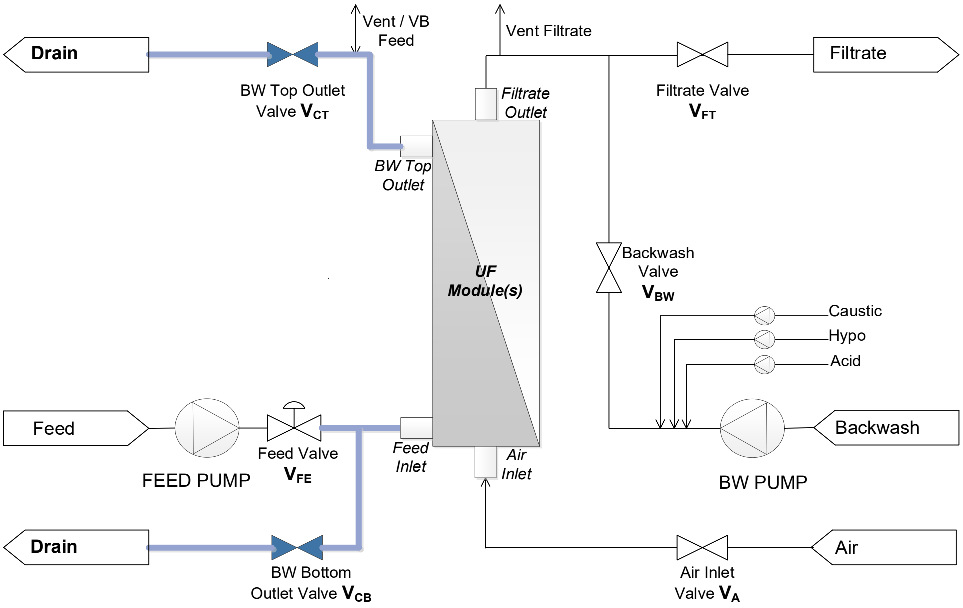

Figure 12: Gravity Drain

5.4 Backwash Bottom

After the gravity drain step, the filtrate continues to flow from the inside of the fiber to the outside but now it is flushed out through the bottom outlet of the module (see Figure 13), ensuring the entire length of fibers have been cleaned. The backwash pump is not stopped in the transition between Backwash Top and Backwash Bottom. The valves must be sequenced to prevent damaging the membranes. Similarly to the Backwash Top step, the duration of the Backwash Bottom is typically 30 – 45 seconds and optionally chlorine might be added to help remove foulants or inhibit microbiological activity. The backwash steps can be repeated numerous times depending on the degree of fouling. Monitoring the backwash wastewater quality can be useful to optimize the durations of these steps.

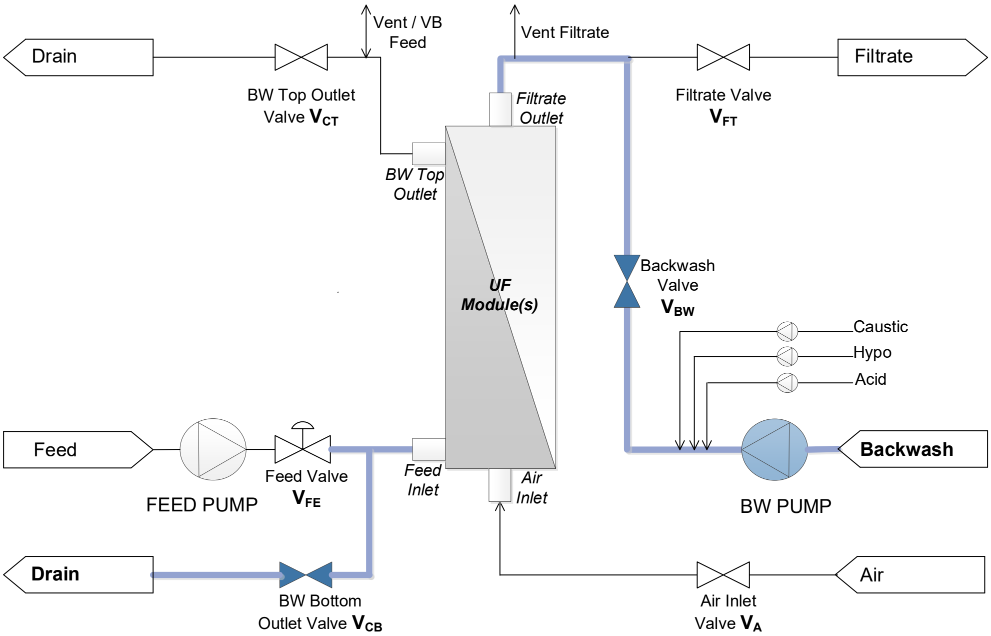

Figure 13: Backwash Bottom

5.5 Backwash Top

After the Backwash Top step, the backwash step is initiated. Filtrate water is pumped backwards, i.e., from the inside to the outside of the fibers, to push the accumulated material off the membrane. Then it is flushed out to waste through the top module outlet (see Figure 14). The duration of the step is 30 – 45 seconds. Sometimes, depending on the application, chlorine might be added to the backwash stream to help remove foulants or inhibit microbiological activity. Air scour can be combined with the Backwash Top step to increase cleaning effectiveness.

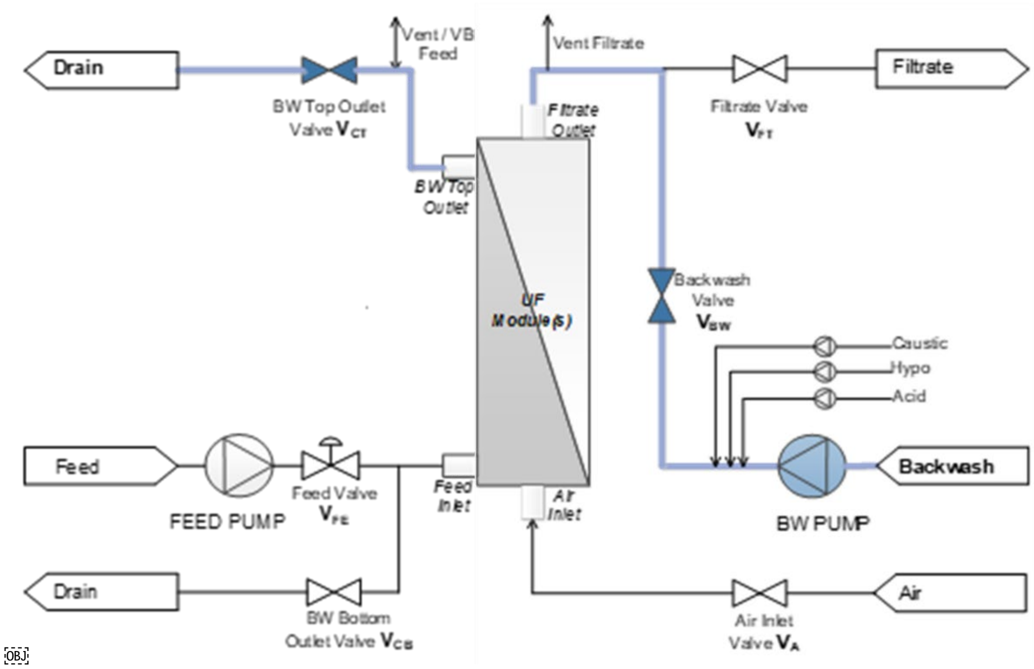

Figure 14: Backwash Top

5.6 Forward Flush

The backwash sequence finalizes with a Forward Flush. In this step, feed water is used to rinse the system to remove remaining solids and the air that might have got trapped in the system during the precedent steps. Water flows on the outside of the fibers (feed side) with the filtrate valve closed, and exits through the module top outlet, as shown in Figure 15. This step typically lasts 30 – 60 seconds or long enough to refill the modules and purge air and water from the outlet. After this, the systems returns to Filtration mode and the cycle starts again.

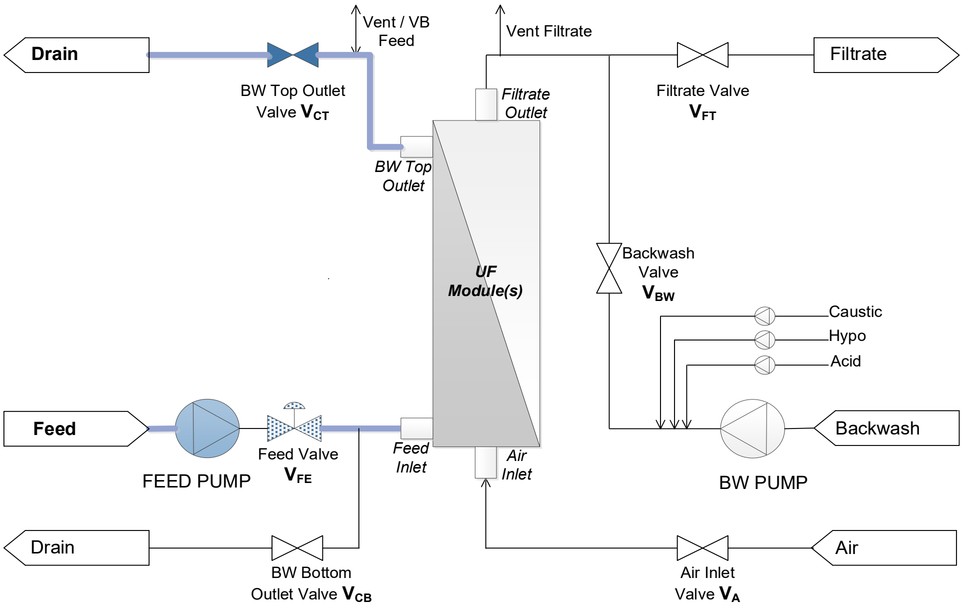

Figure 15: Forward Flush

5.7 Alternative Operation Modes

The following section details several non-standard strategies, as alternatives to the described above, to manage membrane fouling with the aim of simplifying the process, reducing the system footprint and installation costs, reducing the energy and chemical consumption, generating less waste, or increasing the system availability and recovery. These strategies are project specific and need to be validated depending on the application and feed water source and quality. For further details please contact DuPont.

5.7.1 Elimination of Backwash

Depending on the feed water source and quality it might be possible as well to remove the backwash step from the UF operation (and therefore all the equipment associated to it) and rely on regular Air Scour and Forward Flush as the only hydraulic methods to help removing membrane fouling. However, regular chemical cleanings must be still applied. Please contact DuPont for further details.

Some of the benefits of the elimination of the Backwash step are:

- Increased UF system recovery.
- Reduced UF trains size (i.e. fewer UF modules needed).
- Reduced UF system footprint and process complexity (due to the elimination of backwash pumps, tanks, piping, CEB dosing pumps and injection points, etc.).
- Reduced energy consumption.
- Less volume of waste generated

5.7.2 Backwash with RO Brine

In integrated systems where UF is used as pretreatment of RO, it might be possible to backwash the UF system with RO brine, instead of the standard approach using ultrafiltrate water, with no detrimental impact on the UF system performance or membrane integrity. This is only feasible for specific water sources and under certain conditions, and simply refers to backwash and not to chemical cleanings. Please contact DuPont for further details.

Some of the benefits of using RO brine for UF backwash as opposed to ultrafiltrate water are:

- Increased UF system recovery.
- Reduced UF trains size (i.e. fewer UF modules needed).
- Potential to eliminate the equipment associated to backwash pumping, and reduce energy consumption, if the residual brine pressure is used.
- Less volume of waste generated.

6 Water Chemistry and Pretreatment

6.1 Water chemistry

As introduced in the previous chapter, ultrafiltration is a size exclusion membrane process that rejects particles, pathogens, high molecular weight species, and ultimately lowers turbidity. However, UF does not reject any dissolved salts, dissolved organics, or other species like true color or taste and odor. Feed water can encounter different type of compounds that can lead to membrane fouling. A deeper introduction to fouling is addressed in Chapter 6.

In order to have a comprehensive understanding of the feed water quality and its fouling potential, there are a few key parameters that need to be monitored during operation. This section will introduce these parameters, which are summarized in Table 1 together with their recommended monitoring frequency.

Turbidity: Sediments, clay, silt, small particles, solids etc. cause a liquid to appear turbid, "hazy". These particles can, host or shield microorganisms like bacteria and viruses. Turbidity is measured by the intensity of light that passes through the water sample, and expressed in NTU (Nephelometric Turbidity Units). DuPont™ IntegraTec™ modules provide consistent product water with turbidity values < 0.1 NTU.

TSS (Total Suspended Solids): It is the measure of the total weight of solids contained in a water sample, and is expressed in mg/L. This parameter is more accurate than turbidity (i.e., turbidity usually does not detect very fine particles).

SDI (Silt Density Index): Is a Fouling Index. This parameter provides an indication of the particulate fouling potential of the water (see Figure 16). It is based on the measurement of the time it takes to collect 500 mL of water sample through a paper filter of 0.45 μm at the start of the test (t_i) and after the water has flowed through the filter at 2.1 bar (t_f) for 15 minutes (T). SDI number is calculated by Equation 1:

$$SDI_T = \left(1 - \frac{t_i}{t_f}\right) \cdot \frac{100}{T} \qquad \text{Eq. 1}$$

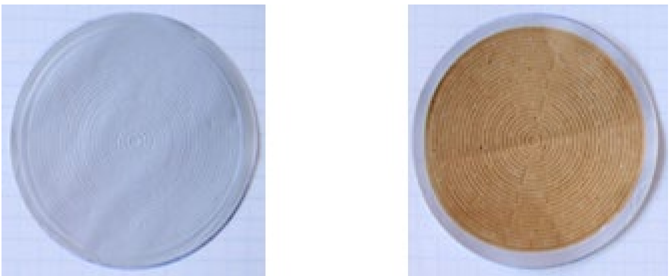

Figure 16: SDI15 filters before and after the test

TOC (Total Organic Carbon): It is the most widely used parameter to determine the organic content in water. It includes Natural Organic Matter (NOM) and synthetic sources. It is indicative of the tendency of the water to cause organic fouling and biofouling in membranes. It is expressed in mg/L. A TOC value > 2 mg/L indicates a high probability of biofouling. The recommended TOC level for RO feed water is < 3 mg/L.

DOC (Dissolved Organic Carbon): Fraction of TOC which is dissolved (filtered through 0.45 μm). Generally TOC and DOC are the same value, except in wastewaters and some surface waters.

COD (Chemical Oxygen Demand): It is a measure of the amount of compounds in a sample which have been oxidized by a strong oxidizing agent. Although inorganic substances such as Fe may also be subject to oxidation, for most natural and industrial waters, the matter to be oxidized is organic in nature.

BOD (Biological Oxygen Demand): Similar to COD except BOD detects substances that are susceptible to biological oxidation which indicates biologically active organics. Therefore COD & BOD can be used to characterize the organic load of water. Expressed as mg/L of Oxygen.

UV_{254} Absorbance: It is an indirect measurement of NOM, based on the fact that most organics compounds can absorb UV light. Expressed in cm^{-1}. Surrogate of TOC. Above 0.5 cm^{-1} indicates biofouling is likely.

SUVA (Specific UV Absorbance): Ratio between UV_{254} and DOC (if > 4, mostly humic matter; if < 2, indication of algae bloom).

O&G (Oil & Grease, Hydrocarbons): Even in very small quantities i.e., < 0.05 mg/L, it can cause accelerated fouling in membranes.

Iron and Manganese: If they are in oxidized form, behave as particles and can be rejected by membrane systems, but will cause fouling. Iron (Fe) can be naturally occurring (e.g., well waters), coming from corrosion of upstream piping and/or equipment, or residuals from pre-coagulation processes.

Calcium and Magnesium: Hardness in water is due primarily to Ca and Mg ions. Based on hardness, the water can be classified as Soft (up to 60 mg/L as $CaCO_3$), Hard (up to 180 mg/L as $CaCO_3$) and Very Hard (> 180 mg/L as $CaCO_3$). Hardness has no harmful effects on health, but leads to formation of scaling deposits in pipes, equipment or membranes.

Conductivity: The electrical conductivity of water is linearly related to the total dissolved solids (TDS). It is the ability of the water to conduct an electrical current. Expressed in µS/cm.

pH: Is a numeric scale used to express the acidity or alkalinity of the water. Solutions with a pH less than 7 are acidic and solutions with a pH greater than 7 are basic. Pure water has a pH of 7 and is neutral. In water, high pH causes a bitter taste, water pipes and equipment become encrusted with deposits. Low-pH water will corrode or dissolve metals and other substances.

Silica: Can be Reactive Silica (Soluble) or Un-Reactive Silica (Colloidal). Colloidal form can cause fouling in membrane systems.

Table 2: Recommended Water Quality Sampling Program

Parameter	**Units**	**Analytical Method**	**Frequency**	**Sample source**
Minimum Recommended Parameters:				
Turbidity	NTU	APHA 2130B	Weekly	Feed + filtrate
Total Suspended Solids (TSS)	mg/L	APHA 2540D / EPA 160.2	Weekly	Feed + filtrate
Total Organic Carbon (TOC)	mg/L	APHA 5310C	Weekly	Feed + filtrate
Dissolved Organic Carbon (DOC)	mg/L	EPA 415.1	Weekly	Feed + filtrate
Iron, Fe	mg/L	APHA 3120B / EPA 200.7	Weekly	Feed
Calcium, Ca	mg/L	APHA 3120B / EPA 200.7	Weekly	Feed
Magnesium, Mg	mg/L	APHA 3120B / EPA 200.7	Weekly	Feed
Additional Recommended Parameters:				
Conductivity	µS/cm	APHA 2510B / EPA 120.1	Weekly	Feed
Total Dissolved Solids (TDS)	mg/L	APHA 2540C	Weekly	Feed
Total Volatile Suspended Solids (TVSS)	mg/L	APHA 2540E	Weekly	Feed
Total Alkalinity	mg/L as $CaCO_3$	APHA 2320B / EPA 310.1	Weekly	Feed
Total Oil & Grease - Total Fraction	mg/L	APHA 5520C	Weekly	Feed
Silica	mg/L	ASTM D859 - 10	Weekly	Feed
Manganese, Mn	mg/L	APHA 3125B / EPA 200.7	Weekly	Feed
Sulfate, SO_4	mg/L	ASTM D516 / EPA 300	Weekly	Feed
UV-254	Abs/cm	APHA 5910B	Weekly	Feed
Chlorophyll-A	mg/m_3	APHA 10200H	Weekly	Feed
Total Coliform	CFU/100 mL	Cultivation APHA 9215 & 9222	Weekly	Feed + filtrate
Total Viable Counts (22°C, 37°C)	CFU/100 mL	Cultivation APHA 9215 & 9222	Weekly	Feed + filtrate
Enterococci/ E-Coli	CFU/100 mL	Cultivation APHA 9215 & 9222	Weekly	Feed + filtrate
Adenosine Triphosphate (ATP)	mg/L	ASTM D4012 - 81	Weekly	Feed + filtrate
Parameters In-Line or by Handheld Instrumentation:				
Turbidity	NTU	ASTM D6855 & D6698	Daily	Feed + filtrate
Conductivity	µS/cm	ASTM D1125	Daily	Feed
pH	--	ASTM D1293	Daily	Feed
Temperature	°C	-	Daily	Feed
Silt Density Index	--	ASTM-4189-95	Daily	Feed + filtrate

DuPont™ IntegraTec™ Ultrafiltration Modules designs are based on qualified feed water conditions as shown in Table 3. The UF modules can tolerate period excursions in feed water quality as shown as the maximum recommended. If the feed water quality is outside of the design basis range shown below, a pilot study should be operated to confirm performance or pretreatment must be considered. If the system is designed and installed to the qualified conditions below but the feed water quality is not maintained DuPont Water Solutions should be consulted.

Table 3: Qualified Feed Water Quality Parameters

Parameter	**Unit**	**Desirable**	**Maximum Recommended1**
Turbidity	NTU	< 50	300
TSS	mg/L	< 20	100
TOC	mg/L	< 10	40
COD_{Mn}	mg/L	< 20	60
Oil & Grease	mg/L	0	< 2
Particle Size	micron	< 150	300
pH continuous	-	6-9	2-11
pH cleaning	-	2-11.5	1-12
Temperature	°C	< 35	40
Feed Pressure	bar	< 3	6.25 @ 20°C
TMP	bar	< 1	2.1
Cl_2 continuous	mg/L	<0.5	200
Cl_2 cleaning	mg/L	2,000	5,000

[1] Note: Maximum values recommended refer to continuous operation, consult your local representative for values beyond those shown.

6.2 Ultrafiltration Pretreatment

Depending on the feed water characteristics pretreatment might be needed in combination with the UF process. Dissolved substances are not removed by UF membranes, so they must be transformed into particulate form if they are the target of the UF process.

Otherwise, very little pretreatment is required if microorganisms and particles are the target contaminants. Prefilters (100 – 300 µm) need to be installed upstream the UF process to protect the UF system from large particles, sand, etc. See Table 4 for strainer selection guidelines. A variety of technologies can be used such as self-cleaning screens and bag, cartridge, or disc filters.

Table 4: Strainer selection guidelines

Source Water	Strainer Size[2]
Bore Well / Ground	≤ 300 µm
City / Tap Water	≤ 300 µm
Surface (Pretreated)	≤ 300 µm
Surface (Untreated)	≤ 300 µm
Seawater	100 – 300 µm[3]
Wastewater (Secondary, Tertiary Effluent)	≤ 300 µm

Depending on the type of water or range of feed water parameters other pretreatment technologies such as coagulation/flocculation, clarification/sedimentation, flotation or granular media filtration may also be recommended.

Coagulation/Flocculation: Chemical and Physical process to form particle aggregates (flocs) from silt, clay, colloids, suspended material, microorganisms, NOM (by adsorption in the flocs) for removal in subsequent steps such as clarification, flotation or granular media filtration. In coagulation, chemicals such as alum or ferric salts are added to the water to reduce repulsion forces between particles ("*destabilization*"). This enables particles to become attached to each other. It is achieved by rapid mixing ("*flash mixing*") in order to disperse the coagulant quickly in the water. In contrast, flocculation consists in a low-intensity mixing to increase the rate of agglomeration. Chemicals might be used to assist, such as cationic, anionic or non-ionic polymers.

Clarification/Sedimentation: Basins designed to decrease solids concentration typically after a Coagulation + Flocculation step, or removal of settleable solids from turbid waters without coagulant addition. This pretreatment is typically used in inlet waters with average turbidities > 30 NTU or spikes above 50 NTU. It can achieve clarified water < 2 NTU and SDI < 6. The water retention time in the basins is typically 2 – 4 hours. Types of this pretreatment include:

- **High-Rate Sedimentation (Lamella Settlers):** It uses inclined plates for more efficient removal of solids (by providing a larger settling area), typically at 60° and 5 cm separation. It allows higher loading rates; reduced footprint (65 – 80% compared to conventional clarifiers). Appropriate when inlet turbidity > 50 NTU.
- **Microsand Ballasted Clarification**: Small sand grains are added in the flocculation basin to act as nucleus for floc formation. Increased settling velocity. Reduced time and footprint requirements.

Dissolved Air Flotation (DAF): Solids removal occurs at the surface of the clarifier, through flotation, rather than at the floor (i.e., clarified water is removed from bottom, instead of from top). Smaller footprint than conventional settlers. DAF is ideal for removal of light particles with slow settling time (e.g., coagulated NOM), algae or Oil & Grease, when turbidity < 50 NTU. Micro air bubbles (~50 µm) adhere or push-up the flocs at the DAF inlet and force them to float. It includes Coagulation + Flocculation chambers. It can achieve clarified water < 0.5 NTU.

[2] Recommended for initial specification, and to be reviewed against site-specific raw water quality and project drivers.

[3] Strainer size of 100 µm or lower is recommended to control the growth of barnacles and mussel larvae inside the UF system pipes, as well as to prevent sand particles to reach the UF membranes.

Granular Media filtration: It is the oldest (4000 BC) and most commonly used pretreatment process. The water flows through one or more layers of porous granular medium (e.g., sand, pumice, anthracite) to remove suspended solids. Typically, it removes 90 – 99% of the solids. There are different types of granular media filtration:

- **Single-Medium**: Typically sand or anthracite, only if feed turbidity is < 2 NTU, TSS < 3 mg/L.
- **Multimedia**: Pumice or Anthracite over Sand. It is the most common.

Two-Stage (for > 20 NTU and TOC > 6 mg/L): Typically, 1st stage is coarse single or dual filter (60 – 80% removal) and 2nd stage is polishing dual-media filter which removes 99% remaining fine solids. TOC removal is low, typically 20 – 30% or even up to 50% if a carbon layer is installed at the top. It can achieve outlet turbidity < 0.1 NTU.

In addition, granular media filtration systems can be classified:

As per Driving Force:

- **Gravity Filters**: Need only 2 – 3 meters (6.5 – 9.8 ft) head, housed in open tanks.
- **Pressurized Filters**: need higher pressure; enclosed in steel vessels.

As per Filtration Rate:

- **Slow Sand Filters:** Gravity. Typically < 0.5 m/h (gpm/ft^2) loading rate. Best for feeds < 5 – 10 NTU and TOC < 3 mg/L. They can achieve filtrate turbidity < 1 NTU.
- **Rapid Sand Filters:** they can be gravity or pressurized. Up to 12 m/h (gpm/ft^2). Usually require pre-coagulation. They can achieve filtrate turbidity < 1 NTU.
- **High-Rate Filters:** Pressurized filters. Up to 30 m/h (gpm/ft^2). They can achieve filtrate turbidity < 0.5 NTU with coagulant aid.

As per Direction of Flow

- **Downflow**: It is the most common type. Water flows downwards.
- **Upflow**: Rarer, water flows upwards. Used typically in activated carbon filters or roughing filters

7 Chemically Enhanced Backwash (CEB)

7.1 Membrane Fouling

Fouling in UF process is understood as the phenomenon that leads to a gradual increase in the transmembrane pressure (TMP) for a constant product flow (or vice versa, a decrease in the filtrate flow at a constant feed pressure), typically caused by deposition or adsorption of the contaminants present in the feed stream on the membrane surface or in the inner structure.

Occasionally, fouling of the membrane surface occurs and is caused by:

- Inadequate pretreatment
- Overdosing of upstream process coagulants
- Improper materials selection (pumps, piping, etc.)
- Failure of chemical dosing systems
- Inadequate backwash and unsuitable shutdown
- Improper operational control
- Slow build-up of precipitates over extended periods
- Change in feed water composition
- Biological contamination of the feed or filtrate water
- Oil & inorganic contamination of the feed water

From the point of view of the fouling mechanism, there are basically three categories for fouling, being cake formation, pore adsorption and pore blocking.

Cake Formation normally occurs when the contaminants are too large to enter the membrane pores, so they deposit on the membrane surface and create an additional resistance to the passage of water, resulting in a TMP increase.

Pore Adsorption typically happens when the contaminants are smaller than the membrane pore size, so they deposit on the internal walls of the pores, hence reducing the diameter of the pores and therefore providing also an additional resistance to the flow.

Finally, **Pore Blocking** takes place when the contaminants are of similar size to the membranes pores, so that blocking occurs and therefore the number of actual pores is reduced, providing also an additional resistance to the flow.

According to the nature of the contaminants, the fouling can also be categorized as follows:

Particulate: This type of fouling is caused by organic and inorganic particles, suspended solids, colloids and turbidity present in the feed, which are not in dissolved form, and typically larger than the pore size. This can be reduced by operations upstream the UF system such us coagulation, sedimentation, clarification or media filtration. The common cleaning method for this type of fouling is air scour and backwash.

Biological fouling: This is caused by the attachment and growth of microorganisms on the membranes, which can also lead to the formation of a viscous biofilm. This can be reduced by using in-line chemical feed of chlorine or biocide or by elimination of nutrients by using adsorption (e.g., powdered or granular activated carbon, PAC or GAC), or coagulation upstream the UF system. The common cleaning method for removal of biological fouling is cleaning with oxidizers or biocides (e.g., Cl_2, H_2O_2, SBS). Note PAC is available in different grades and can damage the membranes. If using PAC consult with DuPont TS&D.

Inorganic fouling: This is caused by the precipitation of inorganics on the membrane (e.g., Ca, Mg, Fe, Mn), and can be reduced by using oxidation/precipitation and filtration as pretreatment to the UF or in some cases using low hardness water for the alkali chemically enhanced backwash. The common cleaning method for removal of inorganic fouling is chemically enhanced backwash with acid at pH 2 (e.g., HCl, H_2SO_4, Citric, or Oxalic Acid).

Organic fouling: This is the one of the major causes of fouling in the UF processes and is caused by organics adsorbing on the membrane (silt, organic acids, humic substances), as the majority of these substances are too small to be retained by the membrane and hence go through. This can be reduced by using PAC, GAC, or coagulation upstream the UF system. The common cleaning method for removal of organic fouling is cleaning regimes with alkali at pH 12 (e.g., NaOH).

Table 5: Summary of the fouling types and methods of control

Fouling Type	Cause	Prevention	Cleaning Method
Particles	SS, Colloids, Turbidity	Coagulation, Clarifiers…	Air Scour / Backwash
Biological	Microorganisms growth	Bacteriological Control (e.g., Cl_2 in line). Elimination of nutrients (PAC, GAC, Coagulation,…)	CEB/CIP with oxidizers/biocides
Inorganic	Inorganic precipitation (e.g., Fe, Mn, Ca)	Oxidation/Precipitation + Filtration. Use low hardness water for CEB Alkali.	CEB/CIP Acid @ pH ~ 2 (e.g., HCl, H_2SO_4, Citric Acid, Oxalic Acid…)
Organic	Organics adsorption (silt, organic acids, humic substances,…)	Coagulation, PAC, GAC,…	CEB/CIP Alkali @ pH ~ 11 – 12 (e.g., NaOH)

7.2 Chemically Enhanced Backwash (CEB)

CEB operation refers to a Chemically Enhanced Backwash, where chemicals (e.g., chlorine, acid or base) are added in the Backwash stream in order to increase the cleaning effectiveness. The type of chemical used depends on the foulant (refer to Table 4 above), which might be a combination of different ones or change seasonally. The frequency of a CEB is dependent on the feed water quality, but typically is once per day to once per week. For high quality feed waters it may not be required.

The CEB process is typically programmed to occur automatically at a preset frequency but this can be field adjusted after gaining site specific operating experience. Alternatively it can be initiated based on a TMP set point. The CEB is performed using UF filtrate.

The CEB is performed following the same steps of a normal backwash sequence except a soak step is added after the addition of the chemicals, for 5 – 20 minutes, to allow time for the chemicals to react with contaminants that have attached to the membrane surface or penetrated the fiber wall. It is recommended however to invert the order of the backwash steps, i.e., backwash bottom first and then backwash top as the second step, to make sure that the system remains filled with the chemical solution during the soaking time. Intermittent air scour (e.g., 5 – 10 seconds every 5 minutes) can be applied as well during the soak step to increase effectiveness.

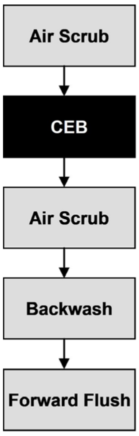

Figure 17: CEB Chart

After the soak a routine backwash including air scour, gravity drain, top and bottom backwash, and forward flush is performed to remove any remaining particulates and purge residual chemicals. After a CEB and at the start of the operating step, the initial filtrate produced might need to be sent to waste to remove residual chemicals. This step is dependent on the system piping and valve design and the downstream requirements for the filtrate. In addition, the CEB can be performed at reduced flux than that used for standard backwash (e.g., 80 Lmh).

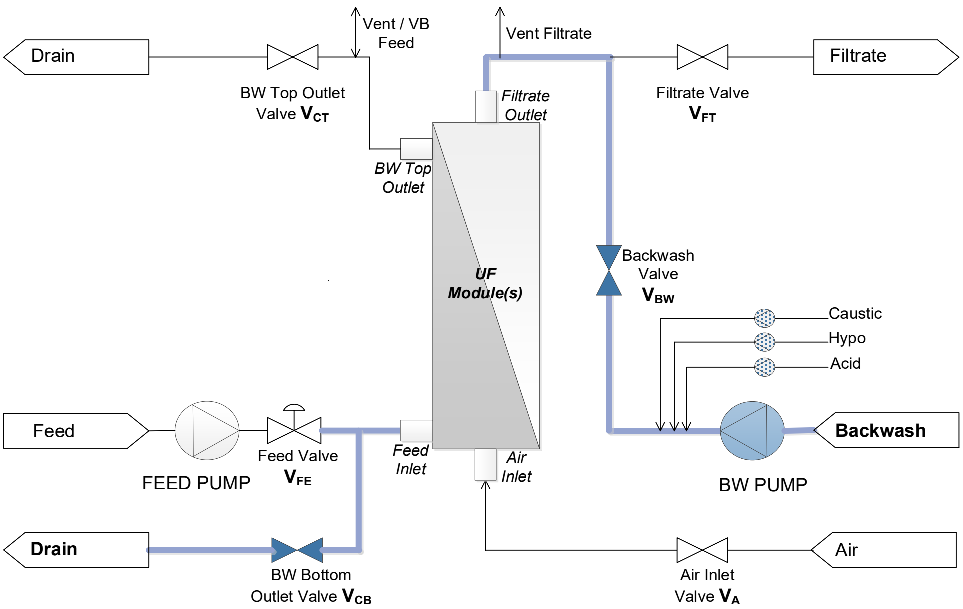

Figure 18: CEB A/B Process Flow

7.3 Alternative Cleaning Protocols

The following section details several non-standard strategies, as alternatives to the described above, to manage membrane fouling with the aim of simplifying the process, reducing the system footprint and installation costs, reducing the energy and chemical consumption, generating less waste, or increasing the system availability and recovery. These strategies are project specific and need to be validated depending on the application and feed water source and quality. For further details please contact DuPont.

7.3.1 Mini-CIP

This approach consists of substituting the standard approach based on regular Chemically Enhanced Backwash (CEB) by Cleanings in Place (CIP) of short duration and is applicable to all water types. For this purpose, the existing auxiliary system used for the standard CIP is employed to perform more frequent but shorter chemical cleanings, called mini-CIP, so there is no need of additional installation or hardware. However, due to the relatively high frequency of mini-CIP (i.e. typically from 1 to 3 times per week), it is recommended to automate the process in order to reduce labor.

The total duration of the mini-CIP is typically 30 minutes and includes a regular Backwash pre-cleaning, a heated chemical solution recirculation step with a soaking period in between (with intermittent Air Scour), and a final Backwash post-cleaning. Note that the mini-CIP substitutes the CEB, not the standard intensive CIP program which still might be needed regularly.

Some of the benefits of the mini-CIP approach as compared to CEB are:

- Increased UF system recovery and availability (as the frequency of mini-CIP and water consumption is typically lower than CEB).
- Lower UF system footprint and system complexity, by reducing the hardware associated to the CEB systems.
- Higher cleaning efficiency, due to the use of recirculation, temperature aid, higher flexibility to use special chemicals and the possibility to use low TDS water (e.g. RO permeate) as solvent.
- Reduced chemical consumption and waste, due to the operation in a closed loop as opposed to CEB's flush-through mode.
- Lower risk of RO membrane oxidation in integrated systems due to the lower system exposure to chlorine as compared to more frequent on-line CEB's.

8 Clean-In-Place (CIP)

8.1 Introduction

The fouling of membrane surfaces results in the gradual performance decline of the UF System in terms of high operating transmembrane pressure, lower sustainable filtrate flow or flux, and/or high chemical and power consumption.

Clean-in-Place (CIP) may be accomplished effectively due to the excellent physical properties and chemical tolerances of the Hydrophilic-Polyvinyldifluoride (H-PVDF) membrane material and module components, which are compatible and resistant to elevated levels of pH, chlorine oxidants, and temperature. Concentration, cleaning time, temperature, intermittent air scour, and hydraulic conditions during the cleaning process are important considerations which will affect cleaning efficiency.

UF system performance should be monitored on a regular and frequent basis. If cleaning is delayed too long, fouling may become irreversible and result in potential physical damage to the UF module or appurtenance equipment. The DuPont™ IntegraTec™ Ultrafiltration Normalization Tool may be used to analyze UF system performance on a normalized basis, to remove or minimize the effects of temperature, pressure, and flow so that the user may differentiate between normal phenomena and real performance upsets due to fouling. The DuPont Ultrafiltration Normalization Tool is available from your local DWS Technical Service.

CIP is most effective if it is tailored to remove the specific fouling problem. Sometimes the wrong choice of cleaning chemicals can make the situation worse. Therefore, the type of foulants on the UF membrane surface should be understood prior to the CIP, so that the most effective CIP cleaning solution and sequence may be used for the procedure. There are different ways to accomplish this:

- Analyze feed water quality.
- Review results of previous cleanings.
- Remove and inspect the feed end of the Module for indication of contaminants.
- Inspect the waste discharge after air scour in the backwash step for indication of contaminants. Sample may be visually inspected or analyzed in laboratory.
- Analyze spent SDI filter paper after grab sample SDI-5 test at UF feed water.
- Destructive autopsy if methods above fail to identify the foulant.

8.2 Safety Precautions

- When using any chemicals indicated here or in subsequent sections, follow accepted safety practices. Consult the chemical manufacturer for detailed information about safety, handling and disposal.
- When preparing cleaning solutions, ensure that all chemicals are dissolved and well mixed before circulating the solutions through the modules.
- During pumping and recirculation of cleaning solutions, observe maximum temperature and pH limits. Please refer to Table 6 below.

Table 6: pH and temperature limits during cleaning

Chemical Type	pH, Max/Min	Temp., Max
Alkaline Solution	12, Max.	35°C (95°F)
Acid Solution	2, Min.	40°C (104°F)

8.3 CIP Requirements

During regular operation, the surface of the fibers of the UF modules may become fouled by particles, biological matter, colloidal particles and/or insoluble organic constituents. Deposits build up on the fiber surfaces during operation, until they result in an increase of TMP to levels or a decrease of normalized filtrate flow that cannot be recovered on sustainable basis by regular backwash and CEBs.

Modules should be cleaned to restore membrane permeability, when one or more of the below parameters are encountered during regular operation, after a CEB event. Permeability is the flux, per unit of transmembrane driving force, and is expressed as Lmh/bar or gfd/psi.

- Normalized Permeability drops by 50%
- Normalized TMP increases by 1 bar (14.5 psi) from initial TMP
- Operating TMP reaches a maximum 2.1 bar (30.5 psi)
- In the event that you do not normalize your operating data, please use the above values for general indication of when to initiate a cleaning event

If delayed too long, the membrane fouling may become irreversible, where cleaning may not restore membrane permeability. Heavily fouled membranes are more challenging to clean as it becomes more difficult for the cleaning chemical to penetrate the membrane surface and flushing the foulants out of the membranes. Furthermore, the time between cleanings may become more frequent as the membranes which are not completely cleaned foul or scale more rapidly.

8.4 CIP Equipment

The equipment for CIP is shown in the CIP system flow diagram below (Figure 19). The materials of construction for selected equipment and ancillaries of the CIP system should be compatible with the pH, chemical types and concentrations, and temperature of the CIP solutions

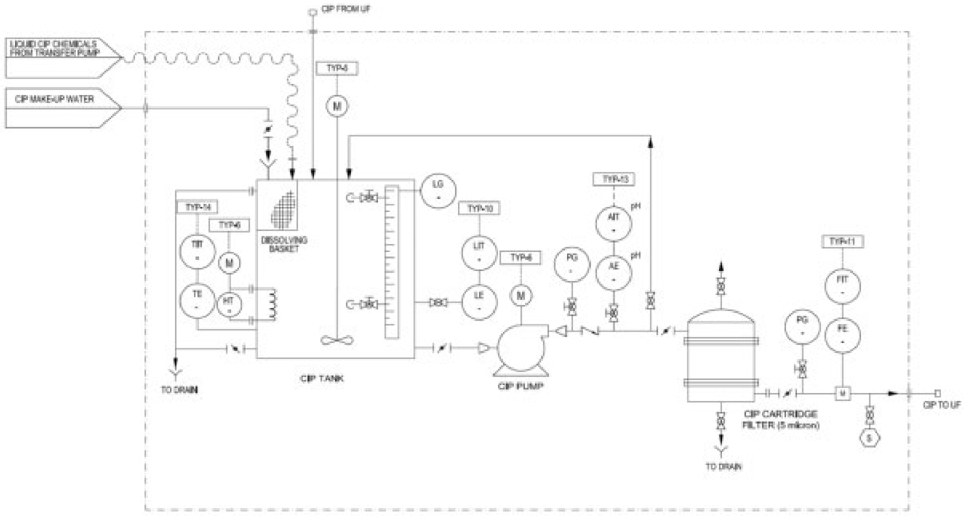

Figure 19: CIP System Flow Diagram

CIP TANK	Chemical Mixing Tank	Polyethylene, Polypropylene or FRP
CIP PUMP	Low-Pressure Pump	316SS, or non-metallic composite
CIP Cartridge Filter	Polypropylene, 5 or10 micron	PVC, FRP, or SS housing
HT	CIP Tank Heater (Optional)	
TIT	Temperature Transmitter	
LIT	Level Transmitter	
LG	Level Gauge	
PG	Pressure Gauge	
FIT	Flow Transmitter	
AIT	pH Analyzer	

1. The CIP Tank may be constructed of polyethylene (PE), polypropylene (PP), or fiberglass-reinforced plastic (FRP). The tank should be provided with a removable cover and a temperature gauge/transmitter. The cleaning procedure is more effective when performed at an elevated temperature. The chemical solution should be maintained in accordance to the pH and temperature guidelines listed in Table 1. It is recommended to not use a cleaning temperature below 15°C (59°F), because of the slower chemical kinetics at low temperatures. Cooling after a heated CIP may also be required in certain geographic regions.

A general rule of thumb used in sizing of the CIP Tank is to use the approximate volume of all of the UF modules and add the hold-up volume in the feed and return lines, within the boundaries of the UF system to be cleaned in one CIP event plus enough volume to maintain a Net Positive Suction Head (NPSH) for the CIP pump.

For example, to clean a system containing ten (10) nos. of DuPont™ IntegraTec™ XP 77 Ultrafiltration modules, to be cleaned in one CIP event, the following calculations may be considered:

a. Volume in UF Modules

V_{module} = 39 L (10.3 gal) / module

$V_{10\ modules}$ = 0.039 m^3 x 10 = 0.39 m^3 (103.03 gal)

b. Volume in Pipes

(assume 10 m (32.8 ft) length of DN50 PN10 (2-in. SCH 80) UPVC pipe)

$$V_{pipe} = \pi r^2 l$$; where *r = radius; l* = length

V_{pipe} = 3.14 x (0.025 m)^2 x 10 m

V_{pipe} = 0.0196 m^3 (5.18 gal)

c. Volume in UF Modules and Pipes (or, CIP Tank Volume)

$V_{10\ modules\ +\ pipe}$ = 0.39 m^3+ 0.0196 m^3= 0.41 m^3 (108.2 gal)

Therefore, the CIP tank should be minimum 0.41 m^3 (108.2 gal).

2. The CIP Pump should be sized for the flows and pressures given in Table 6, making allowances for pressure loss in the piping and across the CIP cartridge filter.

Table 7: Recommended CIP Feed Flowrate per UF module

DuPont™ IntegraTec™ Model	Feed Flowrate (per UF module)		Feed Pressure (at UF module)	
	m^3/h	gpm	bar	psi
SFP-2660	1.0	4.4	< 3.0	< 43.5
XP 51, XP 51 IG; XP 51 IP; XP 51 IP IG	1.5	6.6	< 3.0	< 43.5
XP 77; XP 77 IG; XP 77 IP; XP 77 IP IG	1.5	6.6	< 3.0	< 43.5
XP 55 UXA	1.5	6.6	< 3.0	< 43.5
XTP 100 IG	1.5	6.6	< 3.0	< 43.5

3. Appropriate valves, flow meters and pressure gauges should be installed to adequately control the flow. Service lines may be either hard-piped or use flexible hoses. In either case, the flow velocity should be maintained at 3 m/s (10 ft/s) or less.

4. Ensure that the CIP concentrate and filtrate return lines are submerged in the CIP Tank to minimize foaming.

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8.5 CIP Procedure

In order to restore UF membrane cleanliness and permeability, a Cleaning In Place (CIP) procedure should be performed when:

- Once the permeability falls below 50% during filtration and cannot sufficiently be recovered by the CEB procedure.
- Normalized TMP increases by 1 bar (14.5 psig) from initial TMP.
- Operating TMP reaches a maximum 2.1 bar (30.5 psig).

A CIP is performed by recirculating a chemical batch solution from the CIP tank through the CIP Feed Inlet Valve and returned through the CIP BW Top Return Valve back to the CIP tank. The process is allowing chemical cleaning solution to flow alongside the UF membrane (crossflow), typical duration is 5-10 min for this step. Once the CIP feed recirculation is completed, the CIP Filtrate Return valve is additionally opened, and chemical cleaning solution is now allowed to flow alongside the membrane and also through the membrane into the UF filtrate side. Typical duration is 20-25 min for this step

Once the recirculation has been completed, the CIP pump is stopped, and all valves are closed. Now, the soaking time starts. Typically, soaking time can be 1 hours but can also be much longer, depending on nature of membrane fouling contaminants. After completion of the soaking, the standard BW procedure is used to rinse out the remaining chemicals and prepare the UF system for normal operation.

The cleaning duration for each CIP solution is expected to require about 6 hours, depending on target recycle and soak durations, and actual time required to prepare chemicals and equipment. The permeability of the UF membranes to be cleaned should be measured with online instrumentation for before and after the CIP with each type of solution, to allow for baseline and assessment of chemical cleaning efficiency and indication of the type of fouling. Permeability (Lmh/bar, or gfd/psi) may be measured on normalized terms using the DuPont Ultrafiltration Normalization Tool, or on approximate basis using field measured values of flow and pressure at the feed and filtrate.

Table 8 provides a general valve sequence table for the steps of the CIP procedure. A description of each step of the CIP procedure follows in this section.

Table 8: General Valve Sequence Table for CIP Procedure

Step No.	CIP Step	UF Feed Pump	UF Backwash Pump	UF BW Top Outlet Valve	UF BW Bottom Outlet Valve	CIP Pump	CIP Tank Heater	CIP Inlet Valve (Feed)	CIP Outlet Valve (Concentrate)	CIP Outlet Valve (Filtrate)	CIP Recycle Valve
1	Install CIP Cartridge Filter Elements	O	X	X	X	X	X	X	X	X	X
2	Make-up Cleaning Solution	O	X	X	X	O	O	X	X	X	O
3	Regular Backwash, Pre-CIP	X	O	O[4]	O[4]	O	O	X	X	X	O
4	Remove from Service	X	X	X	X	O	O	X	X	X	O
5	Drain	X	X	O	O	O	O	X	X	X	O
6	Low-flow Pumping	X	X	X	X	O	O	O	O	X	O
7	Recycle	X	X	X	X	O	O	O	O	O	O
8	Soak[2]	X	X	O[3]	X	X	X	X	X	X	X
9	Final Recycle	X	X	X	X	O	O	O	O	O	O
10	Flush Out	X	X	X	X	O	X	O	O	O	O
11	Regular Backwash, Post-CIP	X	O	O[4]	O[4]	X	X	X	X	X	X
12	Return to Service	O	X	X	X	X	X	X	X	X	X

Notes:
X – Valve Closed, or Equipment Off
O – Valve Open, or Equipment On
1 Valve positions and equipment status are dependent on the previous step in the sequence. For example, during Regular Backwash, Pre-CIP (Step 3) the CIP Pump is not required to be On in the stand-alone step, however the CIP Pump continues to be On to allow for mixing of cleaning solution (Step 2) which occurs in-parallel.
2 Valve sequence will differ if low-flow recirculation is practiced during extended soak duration. Refer to Section 7.6, CIP Tips.
3 If intermittent air scour is practiced during Soak step, the BW Top Outlet Valve should be opened to allow venting of air introduced into UF modules. Elevation of system piping will help prevent drain out of CIP solution during this process.
4 Alternating operation depending on the backwashing cycle

1. **Install CIP cartridge filter** elements (5 or 10 µm rating).
2. **Make up cleaning solution.** Preheat cleaning solution to desired temperature, and meanwhile, open the CIP recycle valve to mix the solution with pump and/or agitator. For seawater applications, RO permeate is preferred for the UF CIP make-up solution; however, potable water or UF filtrate may be used if there is no alternative water source. Always add the chemical to the CIP make up water to avoid exothermic reactions.
3. **Regular backwash, pre-CIP.** Conduct a regular backwash of the UF Rack to remove loose contaminants prior to the CIP.
4. **Remove from Service.** Remove the UF Rack to be cleaned from service by normal shutdown procedures. Ensure manual and actuated valves are in correct position prior to the CIP.
5. **Drain out water in the UF Rack.** Residual water in UF rack will dilute the concentration of cleaning solution. Therefore, drain the residual water by opening the BW Top Outlet Valve and BW Bottom Outlet Valve, and close when the UF racks are drained of standing water.
6. **Low-flow pumping.** After the UF Rack is drained of residual water, activate the CIP pump. Pump mixed, pre-heated cleaning solution through the feed side of the UF modules (i.e., filtrate valve closed) at conditions of low flowrate (about half of that shown in Table 7) and low pressure to displace remaining standing water and solids in the UF modules and rack.
7. **Recycle.** Recycle the cleaning solution at the flowrates shown in Table 7. CIP solution continues to be introduced into the UF modules from the feed side. Continue to recycle and allow the temperature to stabilize. Measure the pH of the solution and adjust the pH, if needed – e.g., if pH falls or increases by greater than 1 pH unit from target level. If NaOCl is included in the CIP solution, the recycled solution may also be measured for free chlorine using a portable colorimeter, where NaOCl chemical is replenished if the measured chlorine falls below 75% of target concentration. The recycle step typically lasts 1 hour, depending on extent of fouling. Initially, recycle only through the feed side of the module (i.e., filtrate valve closed) so that the solids accumulated on the membrane surface are flushed out of the system and not pushed back again into the membrane; after 15 – 20 minutes open as well the filtrate valve (while the concentrate/reject valve remains partially open) so that the chemical solution also flows through the fiber and filtrate piping back to the CIP tank (target 10 – 20% filtrate and 80 – 90% concentrate returns).
8. **Soak.** Deactivate the CIP Pump and CIP Tank Heater. Close the CIP inlet, outlet and return valves, and allow the modules to soak. The soak step is typically 2 hours, depending on extent of fouling; sometimes, an overnight soak of 10 – 15 hours is effective for recovery of severe fouling. To maintain a high temperature and to improve cleaning efficiency during an extended soak period, use a slow recirculation rate (about 10% of that shown in Table 7). We recommend intermittent air scour for a few seconds, every 30 minutes of the soak period, to agitate fibers for enhanced cleaning benefits; if intermittent air scour is practiced during soak step, the BW Top Outlet Valve should be opened to allow venting of air introduced into UF modules.
9. **Final Recycle.** Recycle the cleaning solution at the flowrates shown in Table 7. CIP solution is again introduced into the UF modules from the feed side. The final recycle step typically lasts 20 – 30 minutes duration.
10. **Flush out.** After the final recycle period, drain the modules and drain the CIP Tank. Fill the tank with RO permeate (preferred, for seawater applications), potable water, or UF filtrate to prepare for the Flush out step. RO permeate is preferred for seawater applications, to prevent reaction of impurities in the flush-out water with the remaining cleaning solution. Perform the Flush out of the CIP tank and piping by repeat of Low-flow pumping (Step 6) and Recycle (Step 7) for a period of 10 minutes. A plan for discharge of the chemical wastes in accordance to local regulations should be developed prior to performing the CIP.
11. **Regular backwash, post-CIP.** Conduct a regular backwash of the UF Rack to prepare the system for return to service.
12. **Return to Service.**

Form No. 45-D00874-en, Rev 6
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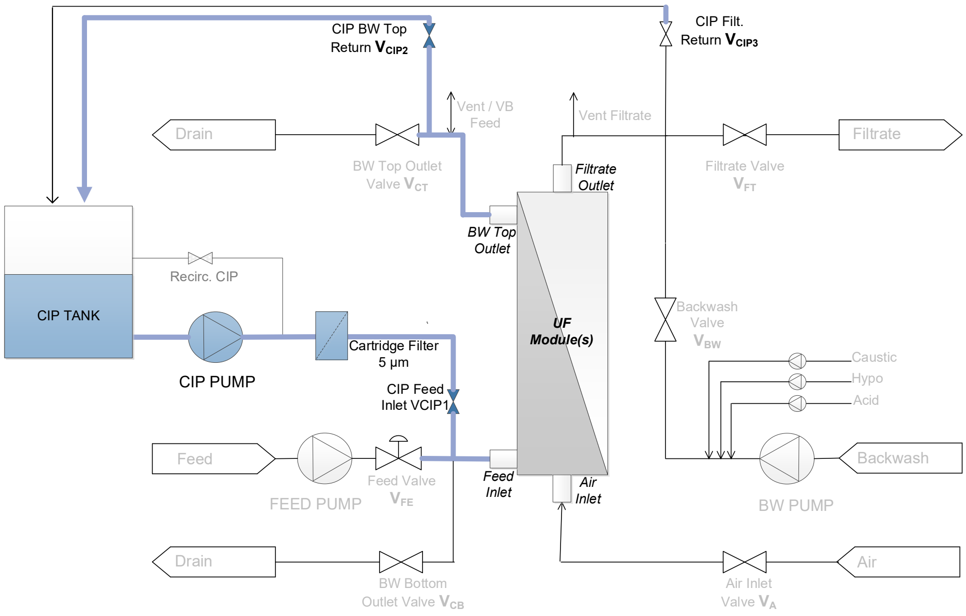

Figure 20: CIP top recirculation

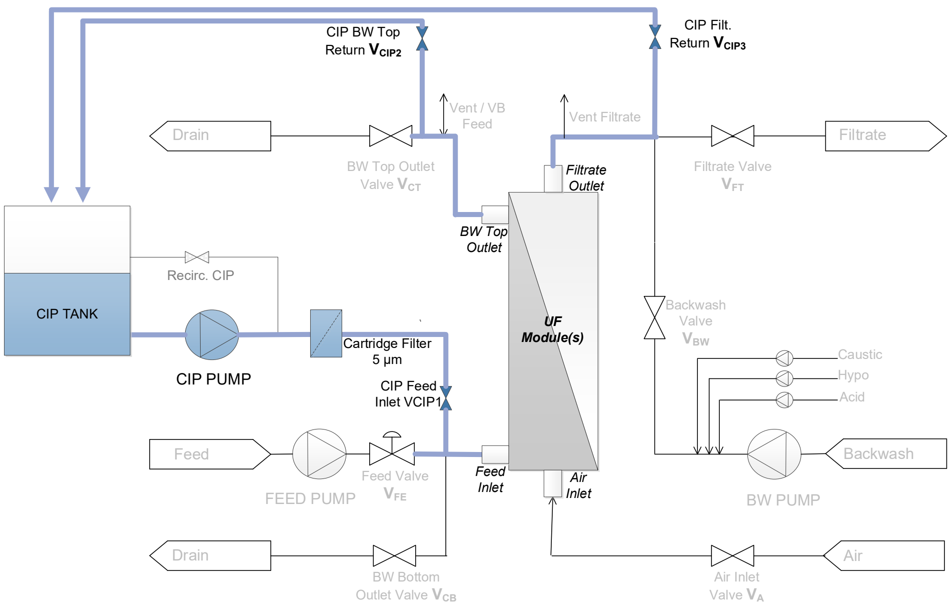

Figure 21: CIP top & filtrate recirculation

8.6 CIP Tips

1. The fouling of membrane modules typically consists of a combination of fouling mechanisms, e.g., a mixture of organic fouling, colloidal fouling and biofouling, which often requires a two-step cleaning program: alkaline cleaning followed by acid cleaning. We recommend alkaline cleaning as the first cleaning step. Acid cleaning should only be applied as the first cleaning step if it is known that only calcium carbonate or iron hydroxide is present on the membrane surface. Acid cleaners typically react with silica, organics (e.g., humic acids), and biofilm present on the membrane surface, which may cause further decline of membrane performance if being introduced first.
2. Always measure the pH during cleaning. If the pH increases more than 1 pH units during acid cleaning, more acid needs to be added. If the pH decreases more than 1 pH units during alkaline cleaning, more caustic needs to be added.
3. Inspect the appearance of the spent CIP solution at various points during the recycle and soak steps. The visual appearance sometimes provides indication of the type of fouling, especially in the case of inorganic metals.

4 Long soak times. It is possible for the chemical cleaning solution to be fully saturated, which allows the foulants to precipitate back onto the fiber surface. In addition, the temperature will drop during this period; therefore the soaking becomes less effective. It is recommended to circulate the solution regularly in order to maintain the temperature (temperature should not drop more than 5°C/41°F) and add chemicals if the pH needs to be adjusted.

5 Fresh cleaning solution needs to be prepared when the cleaning solution becomes turbid and/or discolored. The cleaning is repeated with a fresh cleaning solution.

6 Intermittent air scour immediately before the CIP (prior to Step 5, Drain out water in UF Rack), during, and just at the end of the soaking step (Step 8, Soak), can benefit the cleaning effectiveness in more challenging cases. It might occur that due to the aeration and depending on the system piping layout, some of the chemical solution volume is lost through the module top port; in this case the system must be refilled again with chemical solution using the CIP pump.

7 Thermal Shock should be considered in cold water environments, to prevent damage to UF modules and piping systems in cases where high-temperature CIP solution is introduced into low-temperature system (e.g., Step 6, Low-flow Pumping), or low-temperature flush water is introduced into a warm or heated system (e.g., Step 10, Flush Out). In this case it is recommended to recirculate the solution while it is being heated-up up for a gradual temperature increase. Similarly, at the end of the cleaning, it is recommended to let the system cool down before flushing it out (Step 10 of previous section) with cold water.

8 Use the least harsh cleaning solution possible, including cleaning parameters of pH, temperature, and solution strength.

8.7 CIP Chemicals

Table 9 lists general cleaning chemicals that are effective to recover membrane permeability in most situations. Generic acid cleaners and alkaline cleaners are standard, widely available cleaning chemicals. Acid cleaners are used to remove inorganic precipitates (e.g., including iron), while alkaline cleaners are used to remove organic fouling (e.g., biological matter). Specialty cleaning chemicals may be used in cases of severe fouling, or unique cleaning requirements. For seawater applications, RO permeate is preferred for the UF CIP make-up solution; in cases when RO permeate is not available, please discuss project-specific conditions of water quality with DWS Technical Service to evaluate if potable water or UF filtrate may be used as an alternative water source. Depending on the make-up solution water source, the feed water may be highly buffered (i.e, high alkalinity), where additional acid or base chemical may need to be added to reach the target pH level – which is pH 2 for acid cleans, and pH 12 for alkaline cleans. Also, a softener can be used on the CIP make up water system to remove hardness.

Table 9: General CIP Cleaning Solutions

Cleaning Solution **Targeted Foulants**	**Solution 1** **0.2% (W) HCl, at pH 2, 40°C (104°F) max.**	**Solution 2** **2% (W) Citric Acid at pH 2,40°C (104°F) max.**	**Solution 3** **2% (W) Oxalic Acid at pH 2, 40°C (104°F) max.**	**Solution 4** **0.2% (W) NaOCl + 0.1% (W) NaOH, at pH 12, 35°C (95°F) max.**
Inorganic	Preferred	Alternative	Alternative	
Particulate / Colloidal	Preferred	Alternative	Alternative	Preferred
Microbial / Biological				Preferred
Organic				Preferred
Combined Metals and Organic Complexes		Preferred	Alternative	

Notes:

1. (W) denotes weight percent of active ingredient.
2. Solution 2 (Citric Acid) should be thoroughly flushed from system before return to service due to organics loading.

9 Operation Process

9.1 Instruments for System Operation

For a proper control and monitoring of the ultrafiltration system, the appropriate instruments must be put in place. Table 9 below shows the usual instruments required for the ultrafiltration system (provided by the equipment manufacturer). The data is typically logged by the plant SCADA system every 1 – 10 seconds

Table 10: Minimum instruments recommended in an Ultrafiltration system

Parameter	Feed	Filtrate	Backwash	CEB	CIP	Air Scour
Pressure	X	X	X	X	X	X
Flow		X	X	X	X	X
Temperature	X				X	
pH				X	X	
Turbidity	X	X				

For a detailed Process and Instrumentation Diagram of a typical UF system using DuPont UF Modules contact DuPont.

9.2 Start Up

The following procedures should be followed for start-up of DuPont™ IntegraTec™ ultrafiltration modules and racks. Manually start the equipment during initial operation. Flush the UF system to remove the storage solution used in shipping before starting the equipment. Target a filtrate flow of 60% of design during initial operations. After 24 hours the filtrate flow can be adjusted to design conditions.

9.2.1 Pre-start checks

1. The UF pre-treatment system should operate properly and the UF feed water should meet the design requirements. Ensure that chemical addition points are properly located and that proper mixing of chemicals in the feed streams can occur. Check the addition of pretreatment chemicals.
2. Verify that the drain/waste collection system is functional
3. Verify that the PLC program is loaded and functioning
4. Complete an electrical system check. Verify that the instrumentation is working and calibration is completed. Calibrate gauges and meters based on manufacturers' recommendations.
5. Clean and connect interconnecting piping. Flush system without modules to remove fabrication debris. During the flushing operation, check all pipe connections and valves for leaks. Tighten connections where necessary.
6. Residual air should be removed from the system during start-up.

9.2.2 Start Up

Check that all valves are closed and pumps are off before starting the system. Start the equipment by following the steps below:

1. Pumps should be aligned, lubricated, and properly rotated.
2. Open valves and start the feed pump
3. Fill system and start a flush

4. Start the backwash pump
5. Set and adjust the backwash pressure
6. Set and adjust the inlet air pressure
7. Set backwash time interval
8. Set air scour time interval
9. Set backwash sequence

9.3 Shut Down

9.3.1 Manual shut down

To conduct a manual shut down open the concentrate rinse valve and flush for 15 seconds. Then stop the feed pump and slowly close the inlet valve

9.3.2 Equipment shut down during automatic operation

The equipment will automatically stop or will not allow automatic operation if the feed pump did not start when operation was initiated or the inlet or filtrate pressure is too high to operate or there is a loss of power. Valves should fail closed.

Please refer to the module storage and preservation steps before shutdown to allow proper module maintenance be performed.

9.4 Integrity Test

9.4.1 Introduction

DuPont UF membranes are considered to be an absolute barrier to most of suspended matter, particles and microorganisms (such as Crypstosporidium, Giardia or even viruses), producing a very high filtrate quality (typically with a SDI < 2.5 and Turbidity < 0.1 NTU).

However, occasionally, a seal or valve may leak or a fiber break during operation, resulting in a loss of integrity. Leaking seals or broken fibers could allow contaminants to pass to the filtrate side and compromise its quality. This is not generally detected by the measurement instruments located in the filtrate side, like turbidity meters, as they are not sensitive enough to detect small leaks.

Therefore, a specific test should be employed to detect and isolate modules (or racks) containing leaks, for subsequent repair. Direct Integrity Testing (as opposed to Indirect Integrity Testing, which are based on the monitoring of some parameters of the filtrate water quality, such us turbidity or particle count) represent the most accurate and reliable way of determining the integrity of a membrane filtration system and is able to detect even small breaches in the membranes.

The Pressure Decay Test (PDT) is an example of Direct Integrity Test. In the PDT, a pressure below the bubble point is applied to the membrane, and the subsequent loss in pressure is measured during several minutes (typically 5 – 10 minutes). An integral membrane will maintain the initial pressure or will show a very slow rate of decay (due to the normal air diffusion through the membrane).

This is based on the Bubble Point Theory. The bubble point of a membrane is referred as the threshold air pressure required to displace water from the membrane pores in a fully wetted membrane. Integrity breaches such as broken fibers or defects on its surface are detected when applying pressures below the bubble point.

The general practice is to carry out the Pressure Decay Test applying a minimum pressure able to detect breaches of 3 microns or less, corresponding to the conservative size of the Cryptosporidium oocyst. The corresponding test pressure is dependent on several factors, such as the intrinsic properties of the membrane fiber and module design, but typically 1 – 2 bar (14.5 – 30 psi) is applied.

In case of an integrity breach, a bubble formation will be observed during the PDT in the clear pipes located in the filtrate side of each Module. It is important to note that a small passage of air is normal due to air diffusion through the membrane. A real integrity breach would result in a significant continuous stream of bubbles, accompanied by boiling water like noise and vibration.

9.4.2 Physical Inspection of Modules

If routine direct integrity testing will be performed it is recommended that the piping design include a transparent filtrate pipe section on each module. The transparent pipe will make it easy to identify modules having integrity issues during the direct integrity test. If large continuous bubbles combined with a failed pressure decay test occur, identify or mark these modules. While the modules are pressurized also inspect the clamps and couplers for leaks around gaskets and seals. A soapy water solution can be applied to detect these types of leaks.

9.4.3 Pressure Decay Direct Integrity Test Procedure

There are two types of membrane integrity testing. In the "Indirect" integrity test methods, a filtrate water quality parameter (e.g., turbidity or particle counts) is monitored to detect compromised membrane units. The advantage of the indirect test methods is that the membrane unit does not need to be taken off-line, and continuous monitoring provides real-time integrity indication. However, they are not as sensitive or accurate as the "Direct" integrity test methods. In the "Direct" integrity test methods, a physical test is applied to a membrane unit to detect leaks. Examples of "Direct" integrity test methods are the Pressure Decay Test, the Diffusive Air Flow Test, the Water Displacement Test, or the Seeding Test.

DuPont recommends the Pressure Decay Test in order to check the integrity of the ultrafiltration membranes, due to its simplicity and sensitivity. The test must be done off-line to the individual UF trains. For municipal/drinking water installations the frequency of testing is set by the local regulatory agency. Once a leak is detected, visual inspection through a transparent pipe is used to identify the leaking module.

The integrity test will be carried out manually on-demand or automatically. Testing is performed after the membrane rack has been cleaned. A fouled membrane could hide some membrane defects.

The procedure for the Pressure Decay Test would be as follows:

1. Take the UF unit, rack or module out of the filtration mode (they should be in clean condition to avoid foulants to interfere in the results). Isolate the rack being tested from other racks in the system. Close the feed and concentrate valves (refer to Figure 17 below). Open the filtrate valve to allow water flow through the transparent pipe.
2. Pressurize the rack using oil free compressed air (note that a blower is not suitable for this purpose, consult DuPont for further details) from the air inlet valve, and slowly raise the air pressure to 1.5 bar (~20 psi). Do not exceed 2 bar (~30 psi). Note that a minimum of 1.25 bar (~18 psi) is required to detect a 3 micron resolution. Displaced water may flow through the filtrate side for approximately two minutes.
3. Close the air inlet valve. Allow the pressure to stabilize.
4. Hold the pressure for 5 minutes (unless duration is specified by the local regulatory agency) to determine whether there are leaks or broken fibers. While the pressure hold test is ongoing visually inspect the modules for leaks. If installed, look for large continuous bubbles in the transparent filtrate pipes.
5. The integrity test is successful if the pressure drop is ≤ 0.05 bar (~0.73 psi) for the 5-minute test or the calculated value as determined by the EPA Membrane Filtration Guidance Manual (2005) for the specific system design.

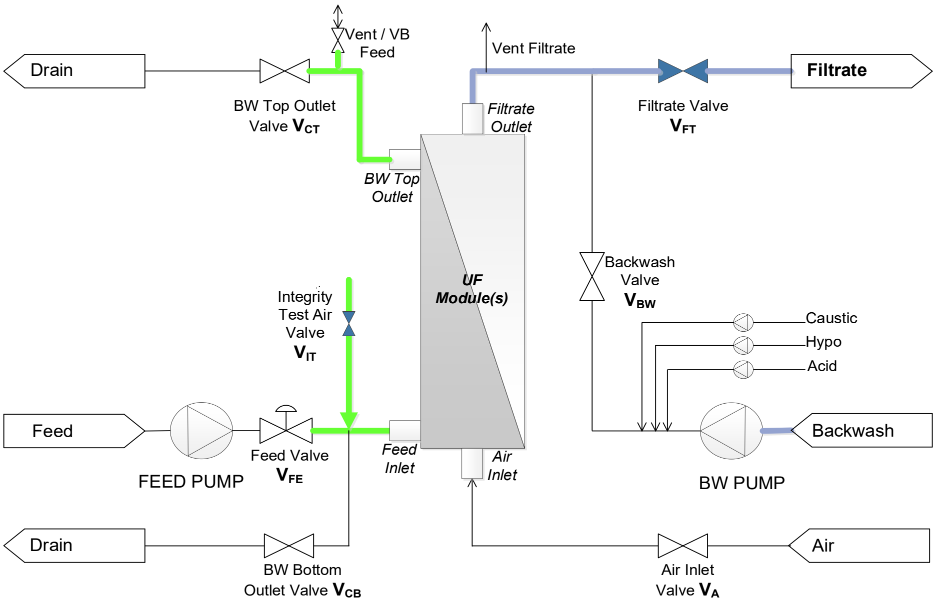

Figure 22: Pressure Decay Test diagram

Example of calculating pressure decay rate: Using an initial feed pressure of 1.5 bar (21.7 psi), an end feed pressure of 1.27 bar (18.4 psi), and test duration of 5 minutes results in a pressure decay rate of (see Equation 5):

$$\frac{(P_{t0} - P_{t5})}{5\ min} = \frac{1.50 - 1.27}{5} = 0.046\ bar/\min\ (0.66\ psi/min) \qquad \text{Eq. 5}$$

If the module exceeds the allowable pressure decay rate, the membrane might be compromised or leaking valves, instruments, pipes, etc. may exist. Check for system leaks or repair the modules and hollow fibers following the fiber test and repair procedure described below.

9.5 Record Keeping

In order to assess the performance of the Ultrafiltration system, it is important that all relevant data are manually recorded and collected on a daily basis (ideally once per shift) for each UF train/rack, independently of the data stored automatically by the plant data acquisition systems. This allows keeping track of the performance, establishing baseline performance, and confirmation of the readings of transmitters and gauges. Besides it is a valuable tool for troubleshooting and warranty claims.

The following list shows the minimum recommended measurements to be taken in an ultrafiltration system:

- Date and Time.
- Feed Water Temperature.
- Pre-Screen Inlet and Outlet Pressure.
- UF Feed Water and Filtrate Pressure (and concentrate pressure in case of Cross-Flow or Bleed-Mode operation). Take measurements before and after events such as Backwash or Chemical Cleanings in order to evaluate the effectiveness of the cleanings.
- Backwash interval.
- Filtrate Flow (and Cross-Flow or Bleed-Flow if applicable).
- Feed and Filtrate Turbidity.
- Feed and Filtrate SDI.
- Backwash flow (and calculate flux) and duration (including Air Scour, gravity drain, backwash top and backwash bottom, and forward flush steps).
- CEB frequency, duration, chemical concentrations used/pH, etc.
- CIP frequency, duration, chemical concentrations used/pH, etc.
- Calibration of all gauges and meters based on manufacturers' recommendations as to method and frequency.
- Any unusual incidents, for example, pretreatment upsets or feed water excursions, integrity failures, fiber repairs, shutdowns, etc.

Refer to Chapter 2 for details of the recommended water quality parameters to be monitored on a regular basis during the operation of the plant.

Examples of data logging sheets are shown in Table 11 below.

Table 11: Example of DuPont UF Operation Log Sheet

DuPont UF Data Log Sheet			
Customer:			
System Information: (pretreatment process, chemical feed type and dosages, etc):			
UF Module Type:	**Number of Racks:**	**Number of Modules/Rack:**	**Membrane Area:**
Date:	**Time:**	**Cumulative hours of operation:**	**Recorded By:**
Parameters	**Unit**	**Recorded Value**	**Comments**
Data Collected			
Temperature (T)	°C or °F		
Pre-filter Inlet Pressure	psi or bar		
Pre-filter Outlet Pressure	psi or bar		
UF Feed Pressure (P_f)	psi or bar		
UF Filtrate Pressure (P_p)	psi or bar		
UF Concentrate Pressure (P_c)	psi or bar		
UF Filtrate Flow / rack (Q_p)	gpm or m^3/h		
UF Conc. Bleed Flow / rack (Q_c)	gpm or m^3/h		
UF Backwash Flow / rack (Q_{bw})	gpm or m^3/h		
UF Forward Flush / rack (Q_{ff})	gpm or m^3/h		
Filtration time per cycle (t_f)	minutes		
Backwash time per cycle (t_{bw})	seconds		
Forward flush time per cycle (t_{ff})	seconds		
Air Scour time per cycle	seconds		
CEB Alkali frequency	hours		
CEB Alkali pH	---		
CEB Acid frequency	hours		
CEB Acid pH	---		
UF Feed Turbidity	NTU		
UF Filtrate Turbidity	NTU		
UF Feed TSS	ppm or mg/L		
UF Filtrate TSS	ppm or mg/L		
UF Filtrate SDI_{15}	%/min		
Performance			
Gross Flux (J)	L/(m^2h) or gfd		
Transmembrane Pressure (TMP)	psi or bar		
Permeability ($L_{N,20}$)	gfd/psi or Lmh/bar		
Equations to Calculate Performance			
Transmembrane Pressure (TMP) = $P_f - P_p$			
Recovery (R) = $(Q_p * t_f - Q_{bw} * t_{bw}) / (Q_p * t_f + Q_{ff} * t_{ff}) * 100$			

Table 12: Example of DuPont UF CIP Log Sheet

DuPont UF CIP Record Sheet

Customer:

System Information: (pretreatment process, chemical feed type and dosages, etc.)

UF Module Type:	**Number of Racks:**	**Number of Modules/Rack:**	**Cumulative hours of operation:**	**Total number of cleaning:**
Date:	**Time:**	**Cumulative hours of operation after last cleaning:**		**Recorded By:**
Item	**Unit**	**First Solution**	**Second Solution**	**Remarks**
Pre-cleaning Air Scour and Backwash				
Backwash Water Source	---			
Backwash Flux	L/(m²h) or gfd			
Air flowrate per module	Nm^3/h or scfm			
Cleaning Chemicals				
Volume of cleaning solution	L or US gal			
Acid (also list type used)	L or US gal			
Caustic soda (%)	L or US gal			
Sodium hypochlorite (%)	L or US gal			
Other Chemicals	L or US gal			
CIP Operating Conditions				
Solution concentration	%			
pH	---			
Temperature	°C or °F			
Circulation flowrate	m^3/h or gpm			
Duration of initial circulation	minutes			
Soaking period	minutes			
Duration of final circulation	minutes			
Final Backwash and Flush/Rinse				
Source of water	---			
Flowrate	m^3/h or gpm			
Duration	minutes			
pH of waste streams	---			

9.6 Data Normalization

9.6.1 Introduction

The temperature of the feed water affects the permeability of a membrane filtration system. At lower temperatures water becomes increasingly viscous (approximately 3% for every Celsius degree); therefore, lower temperatures require increasing the transmembrane pressure (TMP) to maintain a constant flux or reduce the flux through the membrane at constant TMP, as the resistance through the membrane increases. Consequently, this viscosity effect should be considered in the facility design to ensure adequate production capacity in all scenarios and understand the impact to energy consumption.

The term "Normalization" is an industry practice for correcting variations that would otherwise appear as a filtrate flux or TMP change, and lead to misinterpretations of the membrane process performance (e.g., a decrease in membrane permeability (i.e., flux divided by TMP) that would mistakenly be interpreted as a result of a fouling phenomenon, when it is only due to a decrease in water temperature). The technical basis for Normalization is provided in the ASTM D5090 standard, however, membrane manufacturers modify these formulas to allow better calibration and fit to the membrane characteristics of their product as demonstrated in fiber construction and field operating performance.

The basic idea of the Normalization practice is to eliminate the temperature effect from the operational data, so that any deviation in membrane performance at same operating conditions (e.g., same feed water quality, filtration cycle duration, same backwash and chemical washes frequency, etc.) can be related to fouling phenomena. DuPont™ IntegraTec™ UF modules uses 25°C as temperature of reference for data Normalization.

9.6.2 Normalization of Performance Data

DuPont uses a viscosity-temperature correction factor based on the latest expression for the viscosity of liquid water from the International Association for the Properties of Water and Steam (IAPWS, www.iapws.org/relguide/LiquidWater.html).

The Temperature Correction Factor (TCF) follows Equation 2:

$$\mathrm{TCF} = \frac{890}{\left(280.68 \cdot \left(\frac{T_K}{300}\right)^{-1.9}\right) + \left(511.45 \cdot \left(\frac{T_K}{300}\right)^{-7.7}\right) + \left(61.131 \cdot \left(\frac{T_K}{300}\right)^{-19.6}\right) + \left(0.45903 \cdot \left(\frac{T_K}{300}\right)^{-40}\right)} \quad \text{Eq. 2}$$

Where:

TCF: Temperature Correction Factor, dimensionless.

T_K : Temperature in Kelvin degrees (i.e., °C + 273.15).

The numerator is the dynamic viscosity of water at 25°C in μPa· s, the denominator is the viscosity of water at the actual operating temperature. This expression results in a TCF of 1 at 25°C.

Table 13 shows the different values of the TCF from 0 – 40°C (32 – 104°F) at 5°C increments, based on Equation 2 above:

Table 13: Temperature vs TCF

Temperature (°C)	Temperature (°F)	TCF
0	32	0.50
5	41	0.59
10	50	0.68
15	59	0.78
20	68	0.89
25	77	1.00
30	86	1.12
35	95	1.24
40	104	1.36

And Figure 23 depicts TCF values versus Temperature

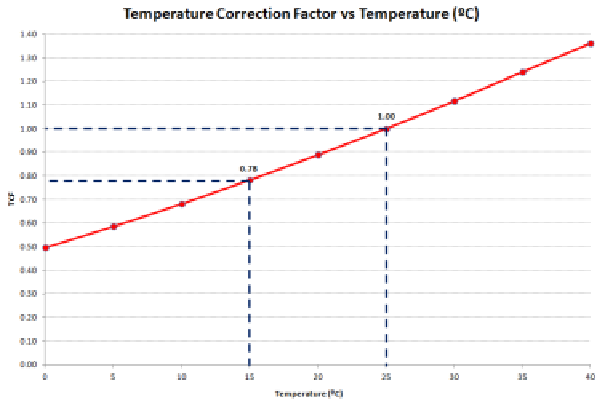

Figure 23: TCF vs Temperature (°C)

The formulas to calculate Normalized TMP and Normalized permeability are shown in Equations 3 and 4:

Normalized TMP = Actual TMP x TCF Eq. 3

Normalized Permeability = Actual Permeability / TCF Eq. 4

(Permeability is defined as operating Flux ($L/m^2 \cdot h$) divided by TMP (bar), with units of $L/m^2 \cdot h \cdot bar$, also expressed as Lmh/bar).

As an example to illustrate the importance of data Normalization, let us consider two hypothetical scenarios of UF plant performance:

Scenario 1: Winter	**Scenario 2: Summer**
Operating Flux: 65 Lmh Temperature: 15°C Temperature Correction Factor (as table and graph above): 0.78 Actual (measured) TMP = 0.40 bar Actual Permeability = 65 / 0.40 = 162.5 Lmh/bar Normalized Permeability (as per Eq. 3 above) = 162.5 / 0.78 = 208.3 Lmh/bar	Operating Flux: 65 Lmh Temperature: 25°C Temperature Correction Factor (as table and graph above): 1.00 Actual (measured) TMP = 0.35 bar Actual Permeability = 65 / 0.35 = 185.7 Lmh/bar Normalized Permeability (as per Eq. 3 above) = 185.7 / 1.00 = 185.7 Lmh/bar

In this example it can be seen that it we look only at the actual values, in summer we seem to have a more favorable scenario, with lower TMP (0.35 vs. 0.40) and higher membrane permeability compared to winter (185.7 vs. 162.5 Lmh/bar). However, if we apply the temperature correction factors, the normalized permeability in summer is actually lower than in winter (185.7 vs. 208.3), which might be an indication of a more fouled membrane, a fact which would have been overlooked had we not considered temperature normalization.

Therefore, data Normalization is a very important tool to assess UF performance, as it allows studying trends of TMP and membrane permeability without the distortion of the temperature effect, so that fouling episodes can be anticipated and the operating parameters and cleaning activities can be adjusted accordingly.

9.6.3 DuPont Ultrafiltration Normalization Tool

The DuPont Ultrafiltration Normalization tool is an Excel based file that allows the plant operator to enter the operating parameters to automatically calculate the normalized values based on the formulas described above. General plant information are the inputs to be filled by the plant operator, which includes parameters like water temperature, UF feed pressure, UF filtrate pressure, flows or feed water quality. The tool also has the option to simulate concentrate-bleed operation.

The tool calculates the Temperature Correction Factor, as well as the Normalized TMP and the Normalized Permeability as described above, and automatically populates the following graphs:

- Normalized Permeability vs. Date
- Normalized TMP vs. Date
- UF Feed and UF filtrate Turbidity vs. Date
- UF Feed and UF filtrate SDI vs. Date

10 Handling and Storage Guidelines

This chapter provides general information for the handling and storage of Modules. The information in this bulletin applies to the DuPont™ IntegraTec™ modules including SFP-2660, XP 51, XP 51 IG, XP 51 IP, XP 51 IP IG, XP 77, XP 77 IG, XP 77 IP, XP 77 IP IG, XP 55 UXA and XTP 100 IG.

DuPont Water Solutions (DWS) recommends that the procedures for long-term shutdown & storage, in particular, be closely coordinated with local DWS technical service to facilitate a positive experience, and to train facility operations & engineering staff

10.1 General

Modules should be handled in such a way to help control the spread of and reduce bio-growth during long-term storage, shipping or system shutdowns. DWS recommends that the modules be shipped and stored in their original factory packaging and loaded into the system racks just prior to start-up. There are cases when the customer may prefer to install the modules onto the racks with significant time before start-up and commissioning; storage guidelines for these cases are also addressed in this chapter. If the module is exposed to air for an extended period of time, the membrane may become dry and at risk to irreversible damage; therefore, it is important to keep the membrane wetted.

10.2 Factory Storage & Shipping of Modules

As part of the quality assurance program, all Modules are tested for integrity and performance ("wet tested") at the factory, prior to packaging and shipment. To control dehydration and biological growth, Modules are shipped wetted and preserved in a non-hazardous standard storage solution containing pH buffered 1 wt% food-grade SMBS. The storage solution inhibits biological growth during storage and shipping of the modules. SDS for these chemicals are available from DWS.

Preservative solution is automatically delivered into the module housings prior to sealing of the module's feed and outlet ports by blinds at the grooved couplings and plug at the threaded air connection. The approximate volume of standard storage solution used at shipping for each module is 2 L (0.5 gal) for SFP-2660; 4 L (1 gal) for XP 51, XP 51 IG, XP 51 IP, XP 51 IP IG and XP 55 UXA; and 6 L (1.6 gal) for XP 77, XP 77 IG, XP 77 IP, XP 77 IP IG and XTP 100 IG. If glycerin is added for freeze protection the holdup module volume will be used. After adding preservative and sealing the openings, the modules are wrapped in plastic bags prior to boxing for dust protection. Precise solution volume and good sealing of the couplings help ensure a stable preservative environment during transportation and storage of new modules.

The wrapped modules are stored in cardboard boxes, with one module per box. A small box containing installation parts is inserted into each cardboard box shipped. Saddle-shaped cushion inserts are located at both ends and along the module to support and protect the modules from damage during shipping and handling. The modules are stored in the horizontal position, with the sealed port connections facing upwards. Labels to identify the port locations and position the boxes are provided on the exterior of the packaging to allow proper storage. To prevent collapse of the boxed modules, stacking is limited to four layers for all products. Depending on the total number of modules and required shipping method, the boxed modules are either palleted or crated for transportation.

Modules must be protected from freezing or excessive heat during shipping and storage. The temperature limits for modules during standard shipping and storage are 1°C (33.8°F) to 40°C (104°F). Avoid abrupt variations in temperature; equalization should be allowed to occur at a maximum temperature differential of ± 1°C (1.8°F) per minute. Irreversible damage to the membrane and damage of the module components may result if the modules are exposed to temperatures outside these limits. If freezing conditions are anticipated during the customer's shipping and storage of modules, please notify DWS at the time of order placement. Glycerine can be added to the storage solution by DWS at the factory prior to shipping to protect the modules under freezing conditions.

Mechanical damage to module housing, membrane, and connections may result if the module, boxed module, pallet, or crate is dropped, and otherwise miss-handled. The modules should be handled with care, with particular attention during transportation.

10.3 Storage of New Modules

Modules are recommended to be shipped and stored in their original packaging separate from the system racks and loaded into the system just prior to start-up. There may be cases where the customer prefers to pre-install the modules on the system racks; for example, to allow factory acceptance testing of packaged or mobile systems prior to shipping, or work scheduling at site to eliminate the separate step for module loading. In cases where pre-installation of modules onto the system racks are preferred for alignment of process/mechanical piping, frame and supports, blank or “dummy” modules are available from DW&PS to assist in alignment and shipping of system racks from the customer’s facility to the project site. It is recommended that seals and plugs for isolation and storage solution containment be saved for future use.

These guidelines should be followed for storage of new Modules:

- Keep modules in original factory packaging. There are cases when the customer may prefer to load the modules onto the racks with prior to start-up & commissioning; guidelines for storage of modules installed on-rack are provided in the Sections 9.4 and 9.5, Short-Term and Long-Term Shutdown & Storage of Used Modules.
- To minimize the potential for leakage of preservative, modules should be stored in horizontal position, with the sealed port connections facing upwards. Labels of the port locations are provided on the exterior of the box to facilitate storage. If leakage is observed, please refer to guidelines for replenishment of storage solution provided in the Sections 9.4 and 9.5, Short-Term and Long-Term Shutdown & Storage of Used Modules.
- To prevent collapse of the boxed modules, limit vertical stacking to four layers for modules.
- Store inside a cool and dry building or warehouse, away from sources of heat, ignition, and direct sunlight. An ambient temperature of 20°C (68°F) to 35°C (95°F) is recommended for ideal storage conditions.
- Temperature limits for modules during shipping and storage is 1°C (33.8°F) to 40°C (104°F). Modules must be protected from freezing or excessive heat during shipping and storage. Avoid abrupt variations in temperature; equalization should be allowed to occur at a maximum temperature differential of ± 1°C (1.8°F) per minute. If freezing conditions are anticipated during the customer’s shipping and storage of modules, please notify DW&PS at the time of order placement. Glycerin may be added to the storage solution by DW&PS at the factory prior to shipping to allow for shipment and storage at freezing conditions.
- Sealed modules may be stored up to 18 months from date of manufacture, at the recommended storage conditions in the original packaging, without additional measures required for storage. If storage exceeds 18 months from date of manufacture, guidelines for confirmation and replenishment of storage are provided in Section 9.5, Long-Term Shutdown & Storage of Used Modules.

10.4 Short-Term Shutdown & Storage of Used Modules

This section provides guidelines for the short-term shutdown & storage of used (installed and operated) Modules and addresses cases where the modules are either (a) stored off-rack as individual modules, or (b) stored on-rack. Short-term is considered as periods where the modules have been drained or used in-service and will remain out of operation for less than 4 days.

Note that the quantities of storage solution required for on-rack storage is greater than for off-rack storage to allow for complete wetting of fibers; off-rack storage allows for horizontal storage which decreases the amount of required solution.

If the modules are expected to be exposed to freezing conditions, glycerin should be added to the storage solution for either short- or long-term shutdown & storage conditions. Refer to Section 9.6, Freeze-Protection of Used Modules

10.4.1 Short-Term Shutdown & Storage, Off-Rack Storage

For cases of short-term shutdown & storage, where the modules will be stored off-rack, and the modules will be placed in service within the next 4 days, SMBS storage solution is not required. Clean water alone is sufficient to keep the fibers in wetted condition to avoid dehydration. Clean water sources may be from potable water or RO permeate. The approximate volume of water required for each module is 2 L (0.5 gal) for SFP-2660; 4 L (1 gal) for DuPont™ IntegraTec™ XP 51, XP 51 IG, XP 51 IP, XP 51 IP IG and XP 55 UXA and 6 L (1.6 gal) for XP 77, XP 77 IG, XP 77 IP, XP 77 IP IG and XTP 100 IG modules.

If the modules have been in-service, a normal system chemical enhanced backwash (CEB) of alkaline, followed by acid, should be conducted before removal of the modules for short-term shutdown & storage. If CEB facilities are not available, then a normal backwash consisting of water and air scour steps should be conducted prior to removal of modules off the rack.

Once the modules are removed water may be fed into the module through the feed port by gravity or low-rate pumping. The module should be kept in horizontal position at time of fill, with the far side filtrate and concentrate ports sealed by blind disc at the grooved couplings. Once the water is added into the module, all service port connections should be sealed tightly using the original blind discs and plugs to retain the solution inside the module. If these parts have not been retained an isolation package can be ordered from the Module Spare Parts List. To minimize the potential for leakage of preservative, modules should be stored in the horizontal position, with the sealed port connections facing upwards. Modules may be kept in the original cardboard boxes. Labels of the port locations are provided on the exterior of the box to facilitate storage.

10.4.2 Short-Term Shutdown & Storage, On-Rack Storage

For cases of short-term shutdown & storage, where the modules will be stored on the rack, and the modules will be placed in service within the next 4 days, clean water alone is sufficient to keep the fibers in wetted condition to avoid dehydration. As for off-rack storage, clean water sources from potable water or RO permeate should be used. The approximate volume of water required for each module is 16 L (4 gal) for SFP-2660; 23 L (6 gal) for XP 55 UXA; 35 L (9 gal) for XP 51 & XP 51 IG; 39 L (10 gal) for XP 77 & XP 77 IG; 49 L (13 gal) for XP 51 IP & XP 51 IP IG and 53 L (14 gal) for XP 77 IP & XP 77 IP IG, 41L (10.8gal) for XTP 100 IG. These quantities of water allow for near to complete fill of the module with water.

If the modules have been in-service, a normal system CEB of alkaline, followed by acid, should be conducted on the modules before short-term shutdown & storage. If CEB facilities are not available, then a normal backwash consisting of water and air scour steps should be initiated prior to short-term shutdown & storage.

DWS recommends that the UF CIP system be used for delivery of the water into the modules from the feed side. Refer to section 7.5 in this document for general procedure.

10.5 Long-Term Shutdown & Storage of Used Modules

This section provides guidelines for the long-term shutdown & storage of used Modules and addresses cases where the modules are either (a) stored off-rack as individual modules, or (b) stored on-rack. Long-term is considered as periods where the modules have been drained or used in-service and will remain out of operation for more than 4 days.

Note that the quantities of storage solution required for on-rack storage is greater than for off-rack storage to allow for complete wetting of fibers; off-rack storage allows for horizontal storage which decreases the amount of required solution.

Re-preserved elements should be visually inspected for biological growth every three months. If the storage solution is not clear, the module should be re-preserved and re-packed as described above. Contact of the SMBS solution with air / oxygen will oxidize bisulfite to sulfuric acid. Therefore, the pH of the solution should be spot checked on random modules every 3 months. Re-storage is required when the measured pH is 3 or lower. For medium to large orders, to avoid inspection of every module, a representative sampling of the total number of modules (e.g. 5%) may be inspected for visual appearance and pH.

If the modules are expected to be exposed to freezing conditions, glycerin should be added to the storage solution for either short- or long-term shutdown & storage conditions. Refer to Section 9.6, Freeze-Protection of Used Modules.

10.5.1 Long-Term Shutdown & Storage, Off-Rack Storage

For cases of long-term shutdown & storage, where the modules will be stored off-rack, and the modules will remain out-of-service for more than 4 days, a storage solution containing pH buffered 1 wt% food-grade SMBS is required to effectively minimize biological growth in the modules during the storage period.

If the modules have been in-service, a normal system CEB and CIP should be conducted on the modules before removal of the modules for long-term shutdown & storage. Refer to Section 7.5 in this document for CIP Procedure. If CEB and/or CIP facilities are not available, then a normal backwash consisting of water and air scour steps should be initiated prior to removal of modules off the rack.

The approximate volume of storage solution required for each module is 2 L (0.5 gal) for SFP-2660; 4 L (1 gal) XP 51, XP 51 IG, XP 51 IP, XP 51 IP IG and XP 55 UXA; and 6 L (1.6 gal) for XP 77, XP 77 IG, XP 77 IP, XP 77 IP IG and XTP 100 IG. For every liter of solution required, 12 grams of food-grade SMBS are added for biostat, and 8 grams of sodium hydroxide and 27 grams of citric acid for pH buffer (quantities refer to active ingredient). Scale-up the preservative formulation to prepare the required volumes of storage solution for number and type of modules to be preserved.

The storage solution may be fed into the module through the feed port by gravity or low-rate pumping. The module should be kept in horizontal position at time of fill, with the far side filtrate and concentrate ports sealed by blind disc at the grooved couplings. Once the target volume of storage solution is added into the module, all service port connections should be sealed tightly using the original blind discs and plugs to retain the solution inside the module. To minimize the potential for leakage of preservative, modules should be stored in horizontal position, with the blanked port connections facing upwards. Modules may be kept in the original cardboard boxes. Labels of the port locations are provided on the exterior of the box to facilitate storage.

10.5.2 Long-Term Shutdown & Storage, On-Rack Storage

For cases of long-term shutdown & storage, where the modules will be stored on the rack, and the modules will remain out-of-service for more than 4 days, a storage solution containing pH buffered 1 wt% food-grade SMBS is required to effectively minimize biological growth in the modules during the storage period.

Similar to off-rack storage, if the modules have been in-service, a normal system CEB and CIP should be conducted before removal of the modules for long-term shutdown & storage. If CEB and/or CIP facilities are not available, then a normal backwash consisting of water and air scour steps should be initiated prior to removal of modules off the rack.

The approximate volume of storage solution required for each module is 16 L (4 gal) for SFP-2660; 23 L (6 gal) for XP 55 UXA; 35 L (9 gal) for XP 51 & XP 51 IG; 39 L (10 gal) for XP 77 & XP 77 IG; 49 L (13 gal) for XP 51 IP & XP 51 IP IG; and 53 L (14 gal) for XP 77 IP & XP 77 IP IG, 41L (10.8gal) for XTP 100 IG. These quantities of solution allow for near to complete fill of the module with water. For every liter of solution required, 12 grams of food-grade SMBS are added for biostat, 8 grams of sodium hydroxide and 27 grams of citric acid for pH buffer (quantities refer to active ingredient). Scale-up as required during the solution preparation procedure to prepare the required quantities of storage solution for number and type of modules to be preserved.

DWS recommends that the UF CIP system be used for delivery of the storage solution into the modules from the feed side. Refer to Section 7.5 in this document for CIP general procedure.

10.6 Freeze-Protection of Used Modules

Modules must be protected from freezing during storage. The temperature limits for modules during storage is 1°C (33.8°F), minimum. Irreversible damage to the membrane and damage of the module components may result if the modules are exposed to temperatures below this limit.

If the modules are expected to be exposed to freezing conditions, glycerin should be added to the storage solution for either short- or long-term shutdown & storage conditions. For cases when freezing is expected and notified to DWS, glycerin is added to the storage solution by DWS at the factory prior to shipping to allow for shipment and storage at freezing conditions. For re-storage by customer, food-grade glycerin should be applied to the storage solution, at the target strengths detailed in Table 14:

Table 14: Summary of the target glycerin strengths

Glycerin (wt%)	Viscosity (cP)	Freezing Point Depression (°C)	Freezing Point Depression (°F)
0.5	1.011	0.07	0.13
3.0	1.074	0.63	1.13
5.0	1.127	1.08	1.94
9.0	1.256	2.06	3.71
12.0	1.365	2.88	5.18
14.0	1.445	3.47	6.25
16.0	1.533	4.09	7.36
20.0	1.737	5.46	9.83
24.0	1.988	7.01	12.62
28.0	2.279	8.77	15.79
32.0	2.637	10.74	19.33
36.0	3.088	12.96	23.33
40.0	3.653	15.50	27.90
44.0	4.443	17.73	31.91
48.0	5.413	20.39	36.70
52.0	6.666	23.22	41.80
56.0	8.349	26.23	47.21
60.0	10.681	29.41	52.94

10.7 Re-Wetting of Dried Out Modules

Modules that have dried out membranes due to improper storage may irreversibly lose water permeability. Re-wetting may be successful with one of the three following methods:

1. Soak modules in 50/50% ethanol/water or propanol/water for 15 minutes.
2. Pressurize the module with UF feedwater to a target pressure of 4.75 bar (68.9 psi). The UF feed pump should be of adequate capacity to meet the target pressure at low flow conditions. During pressurization, slowly close the filtrate until the target pressure is achieved. Close the feed and filtrate valves for hold at the target pressure for 30 minutes. Take care that the filtrate port is re-opened slowly as the feed pressure is released. Do not exceed a transmembrane pressure (TMP) (pressure drop from feed to filtrate side of the membrane) of 2.1 bar (30.5 psi). This procedure should be carried out while the modules are installed on the rack.
3. Soak modules in 1% HCl or 4% HNO_3 solution for 24 hours. During fill of the module, ensure that the module is in a vertical position to allow the escape of entrapped air.

11 Maintenance and troubleshooting

11.1 Introduction

Proper data record keeping and plant performance normalization are indispensable for early detection of performance issues in ultrafiltration systems. Adequate instruments and regular calibration are also critical to ensure accurate readings and anticipate potential operating issues. This section will cover basic aspects for a proper maintenance of ultrafiltration systems as well as some troubleshooting tips.

11.2 Fiber Repair

11.2.1 Introduction

There are several reasons that could lead to fiber breakage:

- Excessive vibrations during shipping, handling or installation.
- Foreign/Abrasive matter entering the UF system (e.g., sand).
- Excessive TMP operation.
- Operation at Flux and/or Temperature above guidelines.
- Water surges (e.g., air trapped in the system).
- Thermal shock (e.g., during CIP).
- Chemical attack (e.g., too extreme pH cleaning)

If a broken fiber is detected, it can be disabled in order to avoid by-pass of feed water to the filtrate side, and hence contamination.

11.2.2 Equipment

The following items are needed to complete the fiber repair procedure:

- DuPont UF Fiber Repair Kit, available from DuPont and which includes concentrate tube plug, glue and repair pins).
- A clean source of water with at least UF filtrate quality.
- Oil-free compressed air (meeting ISO 8573-1, Class 1/3/1 for oil/water/particles)
- Air connection (if module repaired off rack)
- Personal protection equipment (gloves, safety glasses, etc.)

11.2.3 Fiber Test and Repair Procedure

1. Drain the water from the feed side of the modules. Close the filtrate valve to avoid water draining from the filtrate pipe. Remove the top end cap of the module (the bottom end cap is not removed).
2. Close or seal concentrate connections and feed valve. Supply air to module.
3. Provide a clean water source to wet the filtrate/permeate end of the fibers.
4. Pressurize the feed side (outside of membrane) of the wetted membrane with oil free compressed air (a blower is not suitable for this purpose). Slowly increase the pressure to the value identified above. Air will be supplied through the air inlet connection on the module.
5. Introduce water to the top of the fibers to wet the filtrate surface (as shown in Figure 24). If there are compromised fibers, large air bubbles will appear as the pressure is raised. Mark the leaking fiber with a pin or marker where the bubble appears.

Figure 24: Applying water to the filtrate end of the fibers

6. After identifying the broken fiber(s) as shown in Figure 25 , depressurize the module. The top of the module should be free of water.

Figure 25: Identifying leaking fiber at location of large bubble

7. Use gloves for hand protection when working with glue.

Fiber Test and Repair Procedure (Cont.)

8. Apply glue to a pin (shown below in Figure 26). Then insert the pin with glue into the marked fiber bore several millimeters.

Figure 26: Applying glue to pin

9. Allow the repair to set for 5 – 10 minutes before operating and re-testing. Remove the remaining protrusion of the pin by carefully cutting or twisting off the head.
10. Repeat steps 8 - 9 to make sure all broken fibers are repaired.
11. To determine whether the membrane has been properly repaired follow the pressure decay test procedure described above.

For further information and visual demonstration, watch the DVD included in the Fiber Repair Kit, or consult the website www.dupont.com/water/ultrafiltration.html

11.3 Troubleshooting Guide

The following section (see Table 18) lists the major issues that may occur during the operation of the UF system, the most likely cause, and the typical approach to solve it.

Table 15: DuPont UF System Troubleshooting Guide

. Symptom	**Possible cause**	**Solution**
Transmembrane pressure (TMP) high	Modules are fouled	Identify the foulant. Follow the appropriate cleaning procedure as per DuPont Guidelines. Refer to Sections 6 & 7 in this document.
	Flux/Flow too high	Reduce flowrate.
	Improper BW/CEB/CIP programs	Adjust operating conditions (contact DuPont in case of doubt). Refer to Sections 6 & 7 in this document.
	Feed temperature low	Adjust feed water temperature / Reduce operating flux.
	Change in feed water conditions	Check feed water analysis and pretreatment for abnormal changes. Refer to Section 5 in this document.
	Poor quality of chemicals, inefficient chemical cleanings	Evaluate the quality of the CEB/CIP chemicals. Consider using soft water for CIP solution makeup
	Membrane drying	Contact DuPont.
Product flow low	Modules are fouled	Identify the foulant. Follow the appropriate cleaning procedure as per DuPont Guidelines. Refer to Section 5 in this document.
	Abnormal valve open degree	Check the status and open degree of valves
	Flow instruments malfunction	Keep instruments calibrated. Refer to Section 8.1 in this document.
	Feed water pressure low	Diagnose and solve the problem
	Feed temperature low	Adjust feed water temperature / Increase flow.
Poor filtrate quality	Instruments malfunction	Keep instruments calibrated. Cross-check values with handheld devices or off-line laboratory. Refer to Section 8.1 in this document.
	Module integrity problem	Carry out membrane Integrity Test / Fiber repair. Check seals. Check for exposure to extreme temperatures, too high chemical concentration or water hammer. Refer to Section 8.4 in this document.
	Membrane abrasion	Check prefilters, debris in pipes, examine module feed side. Refer to Section 5.2 in this document.
	Membrane aging, drying or damage	Contact DuPont.
Valve failure to open/close	Compressed air pressure low	Increase pressure
	No lubrication in actuator	Inject lubrication to actuator
	Improper place of cap in valve status monitor	Open actuator cap and adjust it
	Feed pump not in service	Check for proper wiring. Restart pump manually and switch to auto mode after normal running.
System cannot start In Auto status	High TMP	Refer to high TMP Symptom above.
	PLC problem	Check PLC
	Tank Level low	Check tank level and level transmitters
CIP Filter pressure drop high	Too high flowrate	Reduce flowrate through filters
	Approaching filter retention capacity. Foulant is being removed from the membranes.	Replace filter. Check chemical solution and replace if necessary. Refer to Section 7 in this document.

12 ADDENDUM

12.1 Terminology

Air Scour	Cleaning method where air is used to shake the fibers and help to dislodge the solids from its surface. Also known as Air Scrub.
Backwash	Hydraulic cleaning method where filtrate water is pumped from the filtrate to the feed side of the membrane in order to remove accumulated foulants. Also known as Backflush or Backpulse.
Bleed-Mode Operation	Flow pattern where most of the feed water will pass through the membrane while the rest will get out of the membrane element directly through the concentrate side (typically 5 – 15% of the feed flow). This concentrate stream will carry part of the contaminants out of the elements and is normally sent to waste.
BOD (Biological Oxygen Demand)	Similar to COD except BOD detects substances that are susceptible to biological oxidation which indicates biologically active organics. Therefore COD & BOD can be used to characterize the organic load of water. Expressed as mg/L of Oxygen.
Chemically Enhanced Backwash (CEB)	Chemical cleaning method, typically initiated automatically, where some chemicals are added into the Backwash stream in order to improve the effectiveness of the cleaning. Usually includes a soaking step.
Clean-In-Place (CIP)	Chemical cleaning method, typically initiated manually, where one or several chemical solutions are consecutively applied in the ultrafiltration trains in order to restore clean membrane condition.
COD (Chemical Oxygen Demand)	It is a measure of the amount of compounds in a sample which have been oxidized by a strong oxidizing agent. Although inorganic substances such as Fe may also be subject to oxidation, for most natural and industrial waters, the matter to be oxidized is organic in nature.
Concentrate	The water stream leaving the membrane system as waste.
Conductivity	The electrical conductivity of water is linearly related to the total dissolved solids (TDS). It is the ability of the water to conduct an electrical current. Expressed in µS/cm.
Cross-Flow Operation	Flow pattern where the concentrate flow exceeds the filtrate flow passing through the membrane (typically in a ratio of 5:1 or higher). The concentrate stream is then typically recycled back to the feed. This allows increasing the flow velocity through the feed channels and therefore achieving a shear force effect that helps to reduce membrane fouling.
Dalton	Unit of mass (Symbol: Da), typically used as unit to measure the molecular weight cut-off of the ultrafiltration membranes.
Dead-End Operation	Flow pattern, also known as “Deposition Mode”, where all the feed volume entering the system flows through the membrane (i.e., there is no waste stream) and is collected in the filtrate side, while the foulants build up on the membrane.
Direct Integrity Test	Physical test applied to a membrane unit to detect integrity breaches.
DOC (Dissolved Organic Matter)	Fraction of TOC which is dissolved (filtered through 0.45 µm).
Feed	The water stream entering the membrane system.
Filtrate	The water stream that goes through the membrane and is free from impurities.

Flux	The throughput of a membrane filtration system expressed as flow per unit of membrane area (e.g., gallons per square foot per day (GFD) or liters per hour per square meter (Lmh).
Fouling	The gradual reduction in filtrate flow at constant pressure (or increase in transmembrane pressure at constant filtrate flow) due to adsorption or deposition of contaminants within or on the membrane.
Hollow-Fiber Module	A configuration in which hollow-fiber membranes are bundled horizontally or vertically and either encased in a pressure vessel or submerged in a tank.
Indirect Integrity Test	Some filtrate water quality parameter is monitored to detect compromised membrane units.
Integrity Breach	Any leak in the membrane system that could lead to by-pass of feed to filtrate side, and hence contamination.
Log Removal Value (LRV)	Filtration removal efficiency for a target organism, particulate, or surrogate expressed as $\log_{10}$ [$\text{Concentration}_{\text{feed}}$/$\text{Concentration}_{\text{filtrate}}$].
Lumen	The bore or inner side of a hollow-fiber.
Microfiltration	A pressure-driven membrane filtration process that typically employs hollow-fiber membranes with a pore size range of approximately 0.1 – 0.5 µm.
Module	This refers to the simplest unit composed of the membranes, the vessel, the end-caps, the feed and air inlets, the filtrate outlet and the waste outlet. Several modules form a membrane train, rack, bank or rack.
Molecular Weight Cut-off or MWCO	Lowest molecular weight (expressed in Daltons) in which 90% of the solute is removed by the membrane.
O&G	Oil & Grease, Hydrocarbons. Even in very small quantities i.e., < 0.05 mg/L, it can cause accelerated fouling in membranes.
pH	It is a numeric scale used to express the acidity or alkalinity of the water. Solutions with a pH less than 7 are acidic and solutions with a pH greater than 7 are basic. Pure water has a pH of 7 and is neutral. In water, high pH causes a bitter taste, water pipes and equipment become encrusted with deposits. Low-pH water will corrode or dissolve metals and other substances.
Permeability	The capability of a membrane to allow the flow of water. It is the best indicator for membrane performance. It is calculated as Flux divided by TMP and expressed in Lmh/bar or gfd/psi, and is typically temperature-corrected (i.e., "normalized") to 20°C or 25°C.
Pore Size	The size of the openings of a porous membrane, expressed either as nominal (average) or the absolute (maximum), typically in terms of microns.
Recovery	The ratio of feed water that is converted to filtrate. Recovery equals to filtrate flow produced by the membrane unit divided by the feed flow and is expressed as percentage.
SDI (Silt Density Index)	Fouling Index. This parameter provides an indication of the particulate fouling potential of the water. It is based on the measurement of the time it takes to collect 500 mL of water sample through a paper filter of 0.45 µm at the start of the test and after the water has flowed through the filter for 15 minutes.
Silica	Can be present as Reactive Silica (Soluble) or Un-Reactive Silica (Colloidal). Colloidal form can cause fouling in membrane systems.
Specific Flux	Synonymous with permeability.
SUVA (Specific UV Absorbance)	Ratio between UV_{254} and DOC (if > 4, mostly humic matter; if < 2, indication of algae bloom).

TMP	Transmembrane Pressure (bar or psi). It is the pressure difference between the feed and the filtrate side of the UF module or rack.
TOC (Total Organic Carbon)	It is the most widely used parameter to determine the organic content in water. It includes Natural Organic Matter (NOM) and synthetic sources. It is indicative of the tendency of the water to cause organic fouling and biofouling in membranes. It is expressed in mg/L.
TSS (Total Suspended Solids)	It is the measure of the total weight of solids contained in a water sample, and is expressed in mg/L. This parameter is more accurate than turbidity (i.e., turbidity usually does not detect very fine particles).
Turbidity	Sediments, clay, silt, small particles, solids etc. cause a liquid to appear turbid, "hazy". These particles can, besides, host or shield microorganisms like bacteria and viruses. Turbidity is measured by the intensity of light that passes through the water sample and expressed in NTU (Nephelometric Turbidity Units). DuPont Ultrafiltration gives consistent product water with turbidity values < 0.1 NTU.
Ultrafiltration	A pressure-driven membrane filtration process that typically employs hollow-fiber membranes with a pore size range of approximately 0.01 – 0.05 µm.
UV_{254} Absorbance	It is an indirect measurement of NOM, based on the fact that most organics compounds can absorb UV light. Expressed in cm^{-1}. Surrogate of TOC.

12.2 Acronyms

ANSI	American National Standards Institute
AS	Air Scour
BOD	Biological Oxygen Demand
BW	Backwash
CDPH	California Department of Public Health
CEB	Chemically Enhanced Backwash
CIP	Clean-In-Place
COD	Chemical Oxygen Demand
DOC	Dissolved Organic Carbon
DWS	DuPont Water Solutions
EDI	Electrodeionization
FRP	Fiberglass-reinforced plastic
GAC	Granular Activated Carbon
GFD	U.S. gallons/ft^2/day
gpm	U.S. gallons/minute
IER	Ion Exchange Resins
kDa	Kilodalton
LMH	Liter/$m^2 \cdot$ h
LRV	Log Removal Value
MF	Microfiltration
MWCO	Molecular Weight Cut-Off
NF	Nanofiltration
NSF	National Science Foundation
NOM	Natural Organic Matter
NPSH	Net Positive Suction Head

NTU	Nephelometric Turbidity Units
OEM	Original Equipment Manufacturers
O&G	Oil & Grease
PAG	Powder Activated Carbon
PDT	Pressure Decay Test
PES	Polyethersulfone
PLC	Programmable Logic Controller
PP	Polypropylene
PS	Polysulfone
PSI	Pounds per square inch
PVDF	Polyvinylidene Difluoride
RO	Reverse Osmosis
SCADA	Supervisory Control And Data Acquisition
SDI	Silt Density Index
SUVA	Specific UV Absorbance
TDS	Total Dissolved Solids
TMP	Transmembrane Pressure
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UF	Ultrafiltration
WAVE	Water Application Value Engine

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