Design and Operating Guidelines for 3M™ Liqui-Cel™ Membrane Contactors

For the following Membrane Contactors
EXF-2.5×8, 4×13, 4×28, 6×28, 8×20, 8×40, 8×80, 10×28, 14×28 and 14×40 Series

SP-2.5×8, 4×13 and 4×28 Series

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3M™ Liqui-Cel™ Membrane Contactors | Design and Operating Guidelines

Table of Contents

Tables

Figures

3M™ Liqui-Cel™ Membrane Contactors | Design and Operating Guidelines

I. SAFETY INFORMATION

Please read and follow all safety information, warnings and instructions in this manual. Failure to follow all product warnings and instructions could cause serious injury and property damage. Retain these instructions for future reference.

Intended Use and Product Selection:

3M™ Liqui-Cel™ Membrane Contactors are intended to remove dissolved gasses and bubbles from compatible liquids or to add gasses to a liquid stream. Liqui-Cel products are for use in industrial separation applications of industrial fluids only, in accordance with the applicable product instructions and specifications. Certain limited Liqui-Cel products are also intended for use in specific Food and Beverage (F&B) applications when used in accordance with product use requirements and instructions. Refer to the specific Liqui-Cel product's performance data sheet to determine whether it includes a F&B designation and can be used for such applications.

3M Liqui-Cel Membrane Contactors may further be used in the production of water for various pharmaceutical products upstream of the final water sterilization step.

Since there are many factors that can affect a product's use, the customer and user remains responsible for determining whether the 3M product is suitable and appropriate for the user's specific application, including user conducting an appropriate risk assessment and evaluating the 3M product in user's application.

Restrictions on Use:

3M advises against the use of these 3M products in any application other than the stated intended use(s), since other applications have not been evaluated by 3M and may result in an unsafe or unintended condition. Do not use in any manner whereby the 3M product, or any extractable or leachable from the 3M product, may become part of or remains in a medical device, drug, cosmetic, supplement, infant formula; or in applications involving life-sustaining medical applications or prolonged contact with internal bodily fluids or tissues.

Explanation of Signal Word Consequences	
⚠ **WARNING**	Indicates a hazardous situation which, if not avoided, could result in serious injury or death.
⚠ **CAUTION**	Indicates a hazardous situation which, if not avoided, could result in minor or moderate injury.
NOTICE	Indicates a situation which, if not avoided, could result in product or system damage.

Read entire product manual. Failure to follow all product instructions and warnings could cause personal injury and/or property damage.

⚠ WARNING

- **To reduce the risks associated with liquid bursting or gas explosion and/or exposure to chemicals and membrane contactor damage:**
  - Do not introduce gas alone into the membrane contactor without liquid in the shell side except when following 3M storage guidelines.
  - Do not exceed maximum operating pressure or temperature limits.
  - Implement workplace safety risk controls according to local applicable laws and regulations.
  - Always use appropriate personal protective equipment (PPE) when installing, servicing, operating, cleaning or disposing of the membrane contactor.
  - All plumbing should be done in accordance with local regulations and code.
  - To prevent buildup of pressure inside the membrane contactor, do not block or valve off all gas/vacuum ports during operation or downtime.
  - Ensure chemically compatible materials of construction are used within system.
  - Always make sure to verify proper connections within the membrane contactor system.
  - Never modify or alter the membrane contactor. Only 3M or parties authorized in writing may make changes/repairs to the equipment.
  - Inspect membrane contactor prior to cleaning or installation. Only use replacement parts supplied by 3M for this product.
  - Inspect the membrane contactor to ensure no leaking, cracking, or other signs of damage on membrane contactor, gaskets and tubing or piping.
- **To reduce the risks of asphyxiation [or other health hazards], accidental gas explosion, or environmental contamination:**
  - Ensure proper system ventilation and discharge of any gases being used in or generated during membrane contactor operation, cleaning and drying, (including sweep gas, vacuum pump or blower discharge,) according to all applicable building codes and regulations.
- **To reduce the risks associated with fire and explosion:**
  - Do not introduce explosive, flammable, toxic or oxidizing liquids or gases in dangerous concentrations into the membrane contactor or the system.
  - Over-pressurization of liquid and gas should be prevented by the installation of proper pressure relief valves/safety systems.
- **To reduce the risks associated with impact, lifting or moving:**
  - Do not attempt to move the system while it contains liquid.
  - Do not attempt to move system while in operation.
  - Use appropriately rated lifting equipment for lifting or moving. Review the product data sheet or operating guide for weights.
  - Always ensure the system is stable, level, and properly secured. Be sure the system cannot tip, roll, fall, slide or make any movement that may cause injury, damage to the unit, or damage to other system components.
  - If needed, use shims to level the system.

⚠ CAUTION

- **To reduce the risks associated with hot surfaces and hot exhaust gases:**
  - Do not touch the membrane contactor or liquid lines during operation or cleaning and drying. Surfaces may be hot.
  - Avoid close proximity to blower exhaust.
- **To reduce the risks associated with environmental contamination:**
  - Exhaust gas should be vented in a safe manner and according to local regulations.
- **To reduce the risks associated with damaging the membrane contactor:**
  - Ensure membrane contactor is properly aligned with piping, and flanges are adequately tightened during use and after cleaning. Always conduct system checks in accordance with installation instructions and facility policies prior to operation.
  - Ensure proper draining and flushing of membrane contactor before maintenance, service, or shipping of membrane contactors.

NOTICE**- To reduce membrane contactor or system damage:**

- Care must be taken not to drop, hit or impact the membrane contactor.
- If the membrane contactor is used with air sweep, then the temperature should not exceed 35°C (95°F). For membrane contactors used with vacuum only this statement does not apply.
- For all membrane contactors, lumen side pressure should never exceed shell side pressure during cleaning and operation. Always refer to operating and cleaning guidelines for the use application.
- To avoid contamination of the process fluid, gloves are recommended when handling the membrane contactors.
- 3M™ Liqui-Cel™ Membrane Contactors should be stored dry and in a sealed plastic bag or shrink wrap material to help prevent the introduction of contaminants into the membrane contactor.
- Store 3M Liqui-Cel Membrane Contactors dry at temperatures < 50 °C (122 °F), but preferably at lower temperature such as <35 °C (95 °F), to not risk reduced lifetime. Membrane contactors should always be stored above freezing temperatures, and if stored at low temperature, they should be allowed to equilibrate to room temperature before use.
- 3M Liqui-Cel Membrane Contactors should be stored in their original box, or other opaque box, and should not be installed where they are exposed to direct sunlight.
- All plastic port extensions should be supported to prevent bending of extensions under excessive piping loads.
- Do not use thread sealant to connect fittings to membrane contactor.
- Use care if using a metal fitting to connect to a plastic connector on the membrane contactor.
- Do not allow membrane contactors containing microporous hollow fiber membranes to come into contact with surfactants, oil, or organic solvents, such as pure alcohols, glycol, acetone, etc., to reduce the risk of membrane wet out. SP-series membrane contactors containing polyolefin membrane are not subject to this restriction.
- To protect the membrane contactors, prefiltration equipment should be inspected and maintained in accordance to 3M Liqui-Cel Membrane Contactors Inlet Water & Sweep Gas Operating Guidelines, in the Technical Resources section at 3M.com/Liqui-Cel.
- Suspended solids, biological contaminants, or the precipitation of soluble or insoluble salts on the membrane surface may lead to membrane plugging.
- Filtered, de-chlorinated, and deionized water is recommended for mixing cleaning solutions. If a pH shift occurs in water containing sparingly soluble compounds of Ca, Mg, Fe, Al, and silica (SiO2) etc. precipitation from the solution could occur, blocking or damaging the membrane. Ensure that your water is free of these compounds.
- Cumulative exposure of the membrane to oxidants, such as ozone, chlorine, hydrogen peroxide, peracetic acid, etc., should be restricted to reduce the risk of membrane oxidation.
- Avoid water hammer (sudden pressure spikes) in system.

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ATTENTION:

Disposal

At end of life, dispose of the membrane contactor or cartridges in accordance with all applicable local and government regulations.

Hazards from Chemicals

The chemicals that User selects to use in connection with the membrane can present their own hazards. User should follow all safety information and related requirements provided by the chemical supplier and applicable regulations, as well as conduct User's own workplace safety, hazard and application assessment. This document cannot and does not address all safety and/or safe handling requirements that different chemicals could present. User is responsible for ensuring that chemicals are only used by persons familiar with their use and hazards (for example, personnel who have received hazardous material training), and who have the appropriate protective equipment as specified in their organization's safety program and the chemical's safety datasheet (SDS). User assumes all responsibility for the suitability and fitness for use as well as for the protection of the environment and for health and safety involving such chemicals.

EU Pressure Equipment Directive (PED) Information

The 2.5×8, 4×13, 4×28, 6×28, 8×20, 8×40, 8×80 and 10×28 Industrial Membrane Contactors are manufactured with Sound Engineering Practice where no CE mark is required due to their small size and low pressures and volumes. The 10×28 in PVDF-lined FRP and stainless steel housings, 14×28 and 14×40 products have a Category I product classification per PED 2014/68/EU and carry a CE mark.

II. Technology Overview

3M Liqui-Cel Membrane Contactors provide efficient dissolved gas control in a compact design. Capable of adding gases (gas adsorption) to or removing (gas stripping) dissolved gases from compatible liquid streams without dispersion. These gas transfer devices utilize hollow fiber membrane technology that may help facilities around the world improve operating efficiency, performance and protect product quality.

A membrane contactor can contain thousands of either microporous or dense asymmetric hollow fibers that are placed inside a contactor housing and are arranged with uniform spacing to allow for high flow capacity and utilization of the total membrane surface area. Because the hollow fiber membrane is hydrophobic, liquids will not penetrate the membrane pores. A higher pressure is applied to the liquid stream relative to the gas stream. Unlike dispersed-phase contactors, such as packed columns, membrane contactors provide a constant interfacial area for transfer over the entire range of flow rates. Several membrane contactor design variants, categorized into three series classifications, are available to meet the needs of a broad range of applications and flow rates.

Table 1: 3M™ Liqui-Cel™ Membrane Contactors by Series

EXF Series	SP Series	MM Series
• Mid to large flow ranges • Typically for water but can be other fluids • Fluid flow outside fiber (shell side) • Utilizes center baffle to enhance flow dynamics • Includes 8×40 and 8×80 products for use in higher pressure applications • Utilizes microporous polypropylene (PP) hollow fiber membrane	• Low to medium flows ranges • Typically for compatible fluids with low surface tension • Fluid flow outside fiber (shell side) • SP-2.5×8, 4×13 and 4×28 series utilize center baffle to enhance flow dynamics • Utilizes polyolefin membrane with dense outer layer that is gas permeable Note: Not all SP Series products are covered in this Design and Operating Guideline. See SP Series Start-up Procedures at 3M.com/Liqui-Cel for SP-0.5×1,1×3,x1×6 and 2×6 Series Membrane Contactors.	• Low flow ranges • Utilizes microporous polypropylene (PP) hollow fiber membrane Note: MM Series products are not covered in this Design and Operating Guideline. See MM Series Start-up Procedures at 3M.com/Liqui-Cel.

Visit our web site at 3M.com/Liqui-Cel for more information on applications and available product options.

A. Membrane Contactor Description and Design

Regardless of the membrane type and the membrane contactor variant used, the separation principle in 3M Liqui-Cel Membrane Contactors differs substantially from other membrane separations such as filtration and gas separation. With 3M Liqui-Cel Membrane Contactors there is no convective flow through the hollow fiber membrane pores. Instead, the membrane acts as an inert support that brings the liquid and gas phases into direct contact without dispersion. The transfer between the liquid and gas phases is primarily governed by the partial pressure difference of each gas species between the two phases. The degassing surface area per unit volume is an order of magnitude higher than traditional technologies such as packed columns, forced draft deaerators and vacuum towers. This greater surface area-to-volume ratio leads to a dramatic reduction in system size at a comparable level of performance. 3M Liqui-Cel Membrane Contactors are mechanical devices that do not require chemicals to operate.

Figure 1: Cutaway of Microporous Hollow Fiber Membrane Showing Liquid and Gas Flow Path

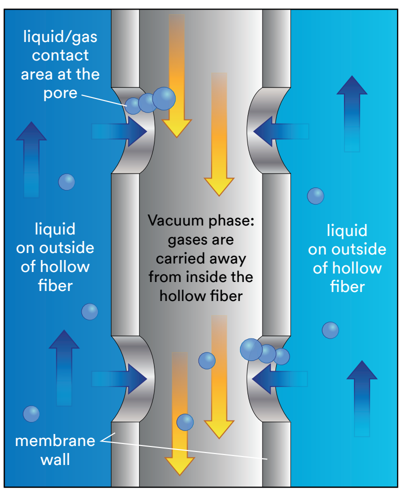
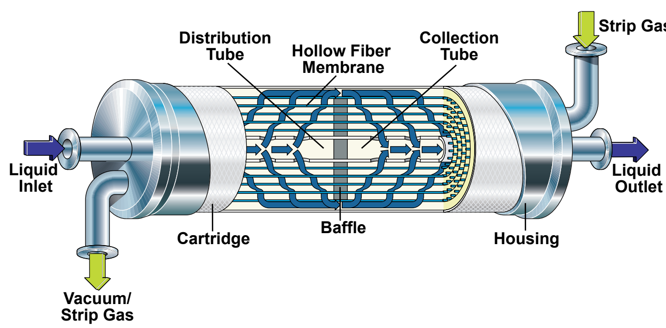


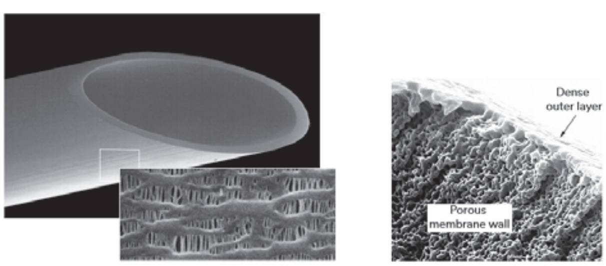
Figure 2: 3M Liqui-Cel Membrane Contactors with Center Baffle Design



Liquid is introduced on one side of the contactor. It flows over the outside of the hollow fiber membrane and around the central baffle. It flows back over the membrane on the second side and exits the contactor in a degassed state. The hollow fibers are open from one end to the other. Removed gases are carried away through the vacuum/strip gas exit port.

B. Hollow Fiber Membrane Types and Selection

Figure 3: Scanning Electron Microscope (SEM) images of hollow fiber membranes



3a. Microporous membrane **3b. Dense asymmetric membrane**

3M™ Liqui-Cel™ Membrane Contactors normally utilize two types of membrane: EXF-series membrane contactors use symmetrically microporous polypropylene hollow fiber membrane, and SP-series membrane contactors use asymmetric polyolefin hollow fiber membrane with gas permeable dense layer(s). Figures 3a and 3b show the structures of the two distinct hollow fiber membrane types.

The fibers used for water applications are microporous whereas low surface tension fluids require the dense asymmetric fiber. The microporous fibers are designated X40 and X50. These membranes are hydrophobic and non-selective, but some variants are more suited for certain applications.

Table 2: Membrane Types and Use

Microporous polypropylene hollow fiber membrane		**Dense asymmetric polyolefin hollow fiber membrane**	
Fiber type	Use	Fiber type	Use
X40	Recommended use for O2 removal from water, but can also be used for CO2 removal	UltraPhobic I (UP I)	Debubbling/degassing low surface tension fluids.
X50	For use for CO2 removal from water, but can also be used for O2 removal	UltraPhobic II (UP II)	Debubbling/degassing low surface tension fluids. “Denser” outer layer of hollow fiber vs. UP I that may help reduce breakthrough potential of compatible fluids (e.g. fluids containing solvents, surfactants)
XIND	Name of hollow fiber membrane used in Industrial version of 3M™ Liqui-Cel™ EXF 10×28 Industrial Series Membrane Contactors. Can be used for O2 and CO2 removal from water.	UltraPhobic II+ (UP II+)	Debubbling/degassing low surface tension fluids. “Denser” outer of hollow fiber layer vs. UP II that may help further reduce breakthrough potential of compatible fluids (e.g. fluids containing solvents, surfactants)

The extremes in operating water temperature and ambient temperature can cause operational issues, especially during on/off cycling or in standby conditions. Condensation inside the hollow fibers reduces the sweep gas flow and subsequently the gas transfer performance. Even if X50 is suggested for CO2 removal, it may not be the best choice if the water temperature is > 30 °C (86° F). X40 fiber should be considered due to its lower water vapor transport (lower porosity) at higher water temperatures.

Not all hollow fiber membrane types are available in all membrane contactors. Please consult data sheets on 3M.com/Liqui-Cel. The sales and technical service team can assist in making the appropriate membrane selection.

III. Important Information on Protecting the Membrane and 3M Liqui-Cel Membrane Contactors

A. General

- Liquid pressure in shell side should always exceed gas pressure inside lumen side.
- Never exceed pressure/temperature limits provided in this guide and on contactor data sheets.

B. Oxidation

Exposing the hollow fiber membrane inside a 3M Liqui-Cel Membrane Contactor to oxidizing species may reduce the life of the contactor. Prior to operation, a risk assessment to identify any potential risk of membrane exposure to oxidizing agents is strongly recommended. It is the sole responsibility of the purchaser and operator to review all potential risks.
There are many possible causes of membrane oxidation induced by various species in the liquid or gas phases. For reference, some common oxidizing species in water are listed in Table 3 below along with their relative oxidative strengths. Increased temperature will accelerate oxidation by these species.

Table 3: Oxidative Potential of Different Species in Water

Oxidizing Species	Relative Oxidative Strength (eV)
F_2	3.10 eV
$OH^{\cdot}$	2.8 eV
$O^{\cdot}$	2.42 eV
O_3	2.07 eV
H_2O_2	1.70 eV
Cl_2	1.36 eV

Note: The above list is not all-inclusive, and the purchaser or operator assumes all responsibility for ensuring no oxidizing species are present.

Our recommendation is to remove free chlorine, ozone and any other oxidizing species from water prior to the 3M Liqui-Cel Membrane Contactor.

Common examples of oxidation risk

Oxygen in air - Air is sometimes used as a sweep gas in a membrane contactor. The oxygen (an oxidizing species) present in the air may cause some deterioration of the membrane hollow fiber, especially at elevated temperatures.

When using air in the sweep gas mode, note the following information:

- Water temperature exceeding 35°C (95°F) increases the risk of oxidizing the membrane.
- Air temperature, if using air sweep, exceeding 35°C (95°F) increases the risk of oxidizing the membrane.

Peroxides and ozone in water - The presence of peroxides and ozone are also important considerations. They are used extensively as disinfectants, germicides and to destroy dissolved oxidizable carbon in many water purification processes. If these species are present in the liquid flowing through the membrane contactor, they will oxidize the membrane.

UV and Hydroxyl radicals in water - UV radiation is commonly used after ozonation step to break down ozone or other oxidizing species to destroy organic carbon and to disinfect water. UV radiation used by itself may also generate potent hydroxyl radicals along with additional hydrogen peroxide in water, as shown below. The hydroxyl radical is a species with a short life span, but it has greater potential to cause oxidative damage.

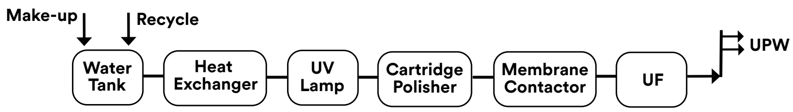
$$H_2O + O_3 + UV \text{-->>} H_2O_2 + O_2$$
$$H_2O + UV \text{-->>} OH^{\cdot} + H^{\cdot}$$
$$2OH^{\cdot} \text{-->>} H_2O_2$$

UV lamps with 185 nm wavelength generate a higher level of free radical than 245 nm UV lamps; radical in high purity water have longer lifespan than in lower water quality with higher TOC. The UV lamp should be set at the lowest power level permitted to reduce the generation of free radicals. The additional presence of ozone can be seen in stainless steel pipe as a discoloration or rouging.

When used in a recirculation loop, the levels of free radical can accumulate after each pass through the UV lamp if there are no TOC's in the water to react with the free radicals. Power levels should be lowered (if permitted) during time of high recirculation.

A typical flow diagram for UPW generation is shown below with membrane degasifier location identified.

Figure 4: Typical Location of 3M™ Liqui-Cel™ Membrane Contactor in UPW Loop with TOC Destruction



When Liqui-Cel contactors are used as membrane degasifier, do not locate them downstream of UV lamps. If it is not possible, there should at least be significant residence time of water between UV and LC contactors. Even placement further downstream of UV may incur oxidation.

Chlorine - Water and or liquids flowing through the contactor may contain high levels of. Chlorine may also cause the membrane hollow fibers to oxidize. It is recommended to remove all chlorine from liquids flowing through the contactor. However, city water containing ≤1 ppm free chlorine at ambient temperatures ≤35°C (95°F) could be used, depending on operating mode. Be aware that some oxidation may still occur. To help reduce effects of membrane oxidation a constant sweep of inert gas should be maintained. In vacuum mode, the vacuum should be left on when Contactors are not in use.

Trace dissolved metals, such as iron and nickel, will act as a catalyst in the presence of chlorine or other oxidizing agents. The result is rapid oxidization of the membrane, especially at warm water temperatures.

C. Surfactants and Organic Solvents

Avoid contact with surfactants and organic solvents with low surface tension (such as alcohols) when using polypropylene membrane as they will render the membrane hydrophilic. The membrane will need to be cleaned and dried before the contactor can be put back into service.

Protecting Other Equipment in Your System

If membrane failure occurs for any reason, liquid water may cross over to the gas side of the membrane. In normal operation, gases exit the membrane system at atmospheric pressure or under vacuum. In case of membrane failure, water will flow out of the vacuum/gas phase ports. In the extreme case, water may stop flowing in its regular path. In the rare event of a major membrane failure and resulting water bypass to the vacuum pump in vacuum or combo mode, a liquid trap and a high vacuum pressure switch are recommended for the vacuum line. A low-pressure alarm switch or a flow switch located at the water outlet of the membrane contactor is also recommended to prevent the pump or other major equipment from running dry.

Maintaining Performance

Since water vapor and other volatile gases will pass through the membrane, the sweep gas will become saturated with the vapor. Depending upon the ambient temperature, condensation could occur in the outlet gas piping. Therefore, the outlet piping should be sloped down and away from the membrane contactors. The piping must be designed to drain this water from the membrane contactors and out of the piping. If the condensate is not removed, it can collect over time in the lumens and reduce the membrane contactor's performance. The condensation rate will depend on the liquid temperature and membrane contact area. The warmer the liquid stream, the higher the water-vapor transport rate. This condensation phenomenon is normal.

IV. Gas Stripping Modes

A dissolved gas can be removed from an aqueous stream with a membrane contactor using one of four different operating modes.

A. Sweep Gas Mode
B. Vacuum Mode
C. Sweep-Assisted Vacuum (Combo Mode)
D. Blower in Suction Mode (Induced Draft Blower) for economical CO2 removal

General guidelines to determine which operating mode to choose for the two main gas removal applications.

Dissolved gas to be removed from water	Suggested mode of operation	Level of Removal (sweep gas purity)
Oxygen	• Combo Mode • Sweep Gas Mode • Vacuum Mode	• < 1 ppb (99.999% N2) • < 10 ppb (99.99% N2) • ~100 ppb (99.9% N2) • 500 - 1000 ppb (no sweep gas)
Carbon Dioxide	• Air sweep Mode • Blower in Suction Mode • Sweep-Assisted Vacuum (Air Combo Mode)	• ≤ 2 ppm (Oil-free, 1-3 µm filtered compressed air) • ≤ 2 ppm (1-3 µm filtered Atmospheric air) • ≤ 1 ppm (1-3 µm filtered Atmospheric air)

Recommended System Instrumentation

Pressure gauges (Isolation valves optional)

- Near contactor water inlet
- Near contactor water outlet
- Gas inlet (e.g. high-pressure nitrogen)
- After gas flowmeter (positive pressure gauge, gas removal 0-2 barg (0 – 30 psig), carbonation 0-10 barg (0 – 150 psig)
- Vacuum line pressure (after gas outlet port)
- Vacuum service water near pump connection (optional)

Flowmeters
- Sweep gas (recommended one per gas manifold or train)
- Water inlet

Pressure regulator
- Gas pressure regulator from 6-10 barg regulate down to 1 barg.

Valves
- Inlet and Outlet Isolation ball valves for water
- Inlet and Outlet Isolation ball valves for gas, except for vacuum and sweep mode
- Inlet manual flow control valve, optional
- Inlet pressure safety relief valve water and gas
- Drain valve on inlet water line
- Drain valves between contactors on vertical mounting (optional)

Vacuum manifold line
- Check valve installed on vacuum pump suction-side
- Manifold shut-off valve (one per train to isolate each train)

Liquid ring Vacuum pump seal/service water
- Check valve
- Needle valve
- Solenoid
- Inlet shut-off
- Compound gage

Pressure switches
- Water inlet high pressure switch to shut down or warn operator
- Vacuum line high pressure switch to warn operator

Temperature measurement
- Water inlet
- Vacuum service water inlet

A. Sweep Gas Mode

Operation Note: In Sweep Gas mode a gas stream flows in the lumen side of the contactor counter-current to the water flow. By choosing a sweep gas (such as N2 or air) that is different from the gas targeted for removal, a partial pressure difference is created between the liquid phase (shell side) and the gas phase (lumen side). This causes the target gas to transfer to the lumen side and be swept out of contactor. The purity of the sweep gas will impact the dissolved gas level that can be achieved at the liquid outlet. A minimum of ISO Class 1 air with an oil content of 0.01 mg/m3 or less is recommended. When using the sweep gas mode, the liquid stream will also become saturated with this sweep gas. The outlet stream of the sweep gas will be humidified and may be saturated with water vapor which may condense in the line.

Gas Side Configuration
Recommended instrumentation for sweep gas mode to 3M™ Liqui-Cel™ Membrane Contactors when using compressed gases (see Figures 5 and 6)

- Pressure regulator valve (PCV-201)
- Needle valve (V-202)
- Pressure indicator (PI-201)
- Flowmeter (FI-201)

If the air or water temperature is > 35 °C (95 °F), the membrane will oxidize faster, resulting in a reduced service life.

Note: A blower increases the air temperature. Air warmer than 35°C (95°F) can have a negative impact on membrane life. For this reason, a blower should not be used to push air into the membrane contactor but used in suction mode to pull air through the membrane contactor. **See section IV D** for more information.

Table 4: Typical Recommended Air Sweep Flow Rates for CO2 Removal *

3M Liqui-Cel Membrane Contactor	SCFM	Nm3/hr
2.5×8	0.25 - 1.5	0.4 - 2.4
4×13	1 - 6	1.6 - 9.5
4×28	1 - 10	1.6 - 15.8
6×28	2 - 12	3.2 - 19
8×20	3 - 18	4.7 - 28.5
8×40	5 - 20	7.9 - 31.7
8×80	Not Recommended for Air Sweep Mode	
10×28	5 - 30	7.9 - 47.5
14×28	10 - 60	15.8 - 95
14×40	Not Recommended for Air Sweep Mode	

* Values shown represent typical sweep flow rates used in most operating systems. However, membrane contactors can be operated at higher sweep rates. For water side configuration and operation see section IV of this guide.

Figure 5. Generic P&ID for Sweep-gas Operation with Two Membrane Contactors in Series: Vertical Mounting (SMC-0113-10-5753)

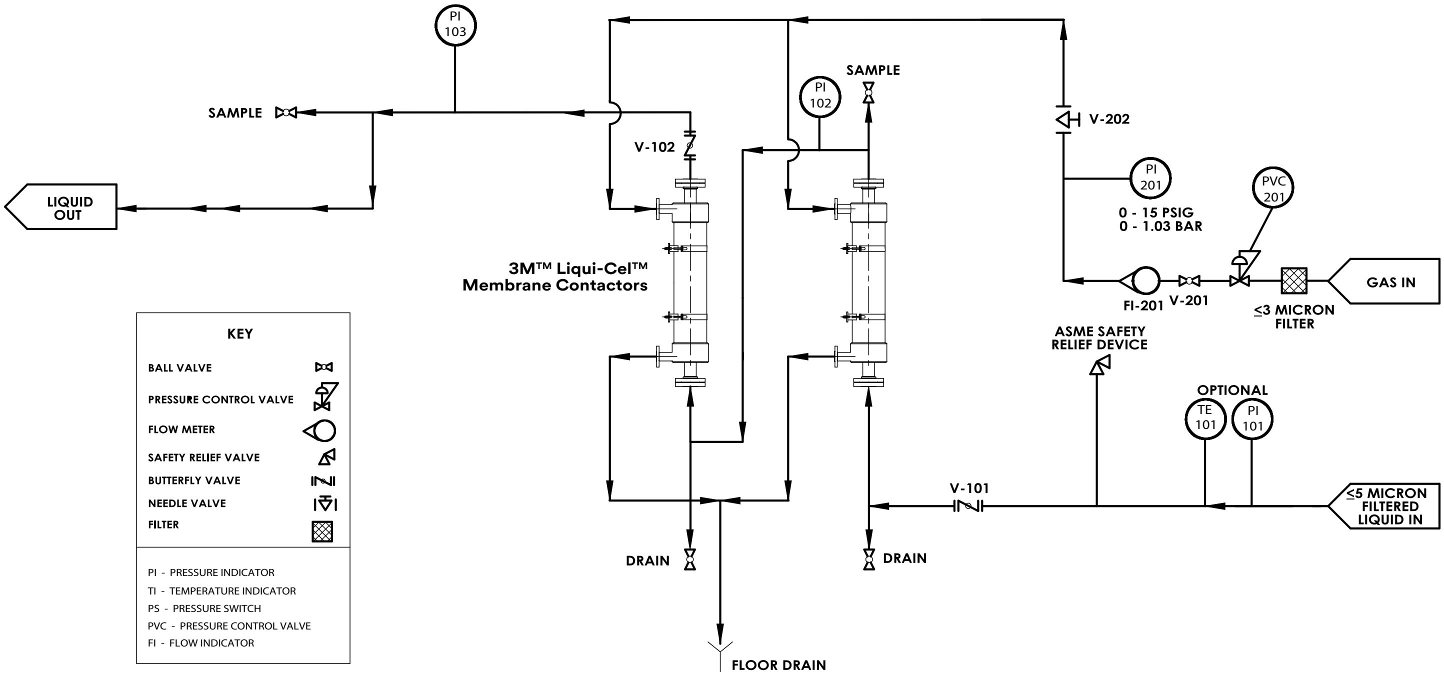
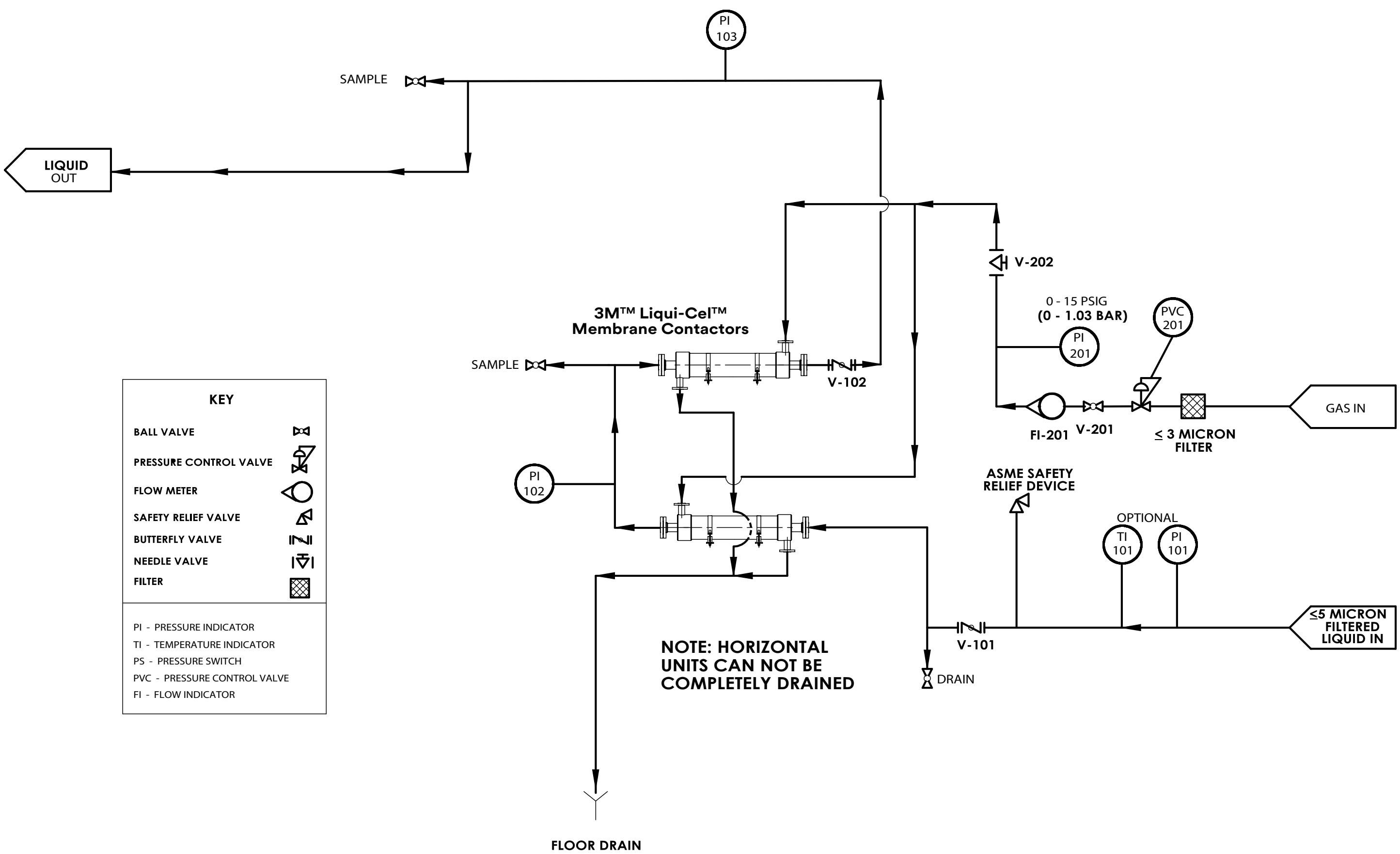


Figure 6. Generic P&ID Sweep-gas Operation with Two Membrane Contactors in Series: Horizontal Mounting (SMC-0113-10-5754)



B. Vacuum Mode

Operation Note: The vacuum method is recommended for total gas control and bulk dissolved gas removal.

A vacuum is applied to the lumen side of the membrane contactor. Vacuum should be drawn from both lumen ports, as opposed to a single lumen port, to improve bulk gas stripping efficiency. When a vacuum is applied, it creates a partial pressure differential between the liquid phase (shell) and the gas phase (lumen). This partial pressure differential drives the transfer of dissolved gases from shell side to lumen side. The removed gases are discharged through the vacuum pump exhaust. Vacuum levels affect removal efficiency. The deeper the vacuum, the lower the dissolved gas outlet concentrations.

Vacuum-Side Configuration

Minimum recommended instrumentation to operate in the vacuum mode (See Figures 7 and 8)

- Vacuum Liquid Trap (optional, system configuration may not require a liquid trap)
- Pressure indicator (PI-301) for vacuum applications
- Check valve (V-302)

The successful operation of a 3M™ Liqui-Cel™ Membrane Contactor degasification system in vacuum or combo mode depends on a well-designed vacuum system (piping and vacuum pump). It is important to follow the recommendations shown below when designing a vacuum system.

Piping

- Design the vacuum line piping size for vacuum service. Threads, pipe dope and pipe tape should be used with extreme caution to prevent air leaking into the vacuum line. Any air leaks will affect degassing efficiency.
- Avoid long runs of piping and loops. Minimize the use of elbows and other potential sources of pressure loss.
- Design the vacuum manifold to handle the vapor load of the entire system. Since water vapor and other volatile gases will pass through the membrane, the lumen side gas will become saturated with the water vapor. Depending upon the ambient temperature, condensation could occur in the gas outlet piping. Therefore, the gas outlet piping should be sloped down and away from the membrane contactors to allow this water to drain from the membrane contactors and out of the piping. If water vapor is not removed, it can collect over time and possibly reduce the performance of the vacuum pump, which will then affect the performance of the membrane contactors. The condensation rate depends on liquid temperature. The warmer the liquid stream, the higher the water vapor transport rate. This condensation phenomenon is normal. Purging the lumen side of hollow fiber with sweep gas or air at high flow rate for 5-30 minutes will facilitate clearing water vapor condensate out of the fibers.

Vacuum Pump Type and Sizing

- Utilize the sizing program or contact a 3M representative to estimate the vapor load to the vacuum pump. Expressed in Actual Cubic Feet per Minute (acfm) or cubic meters per hour (m^3/hr), the vapor load value and the vacuum level will determine the size of the vacuum pump.
- A liquid ring pump is recommended. There are many brands of liquid ring pumps; choose the one that satisfies your needs and ask your supplier for a complete vacuum system, which includes: a vacuum pump, liquid trap, check valve, air bleed valve, gauges and a complete seal water line.

For water side configuration and operation see section IV of this guide.

For Safety and Protecting equipment

In the rare event of a major membrane failure and resulting water bypass to the vacuum pump in vacuum or combo mode, a liquid trap and a high vacuum pressure switch are recommended for the vacuum line. A low-pressure alarm switch or a flow switch located at the water outlet of the membrane contactor is also recommended to prevent the pump or other major equipment from running dry.

Figure 7. Generic P&ID for Vacuum Mode Operation with Two Membrane Contactors in Series: Vertical Mounting (SMC-0113-10-5751)

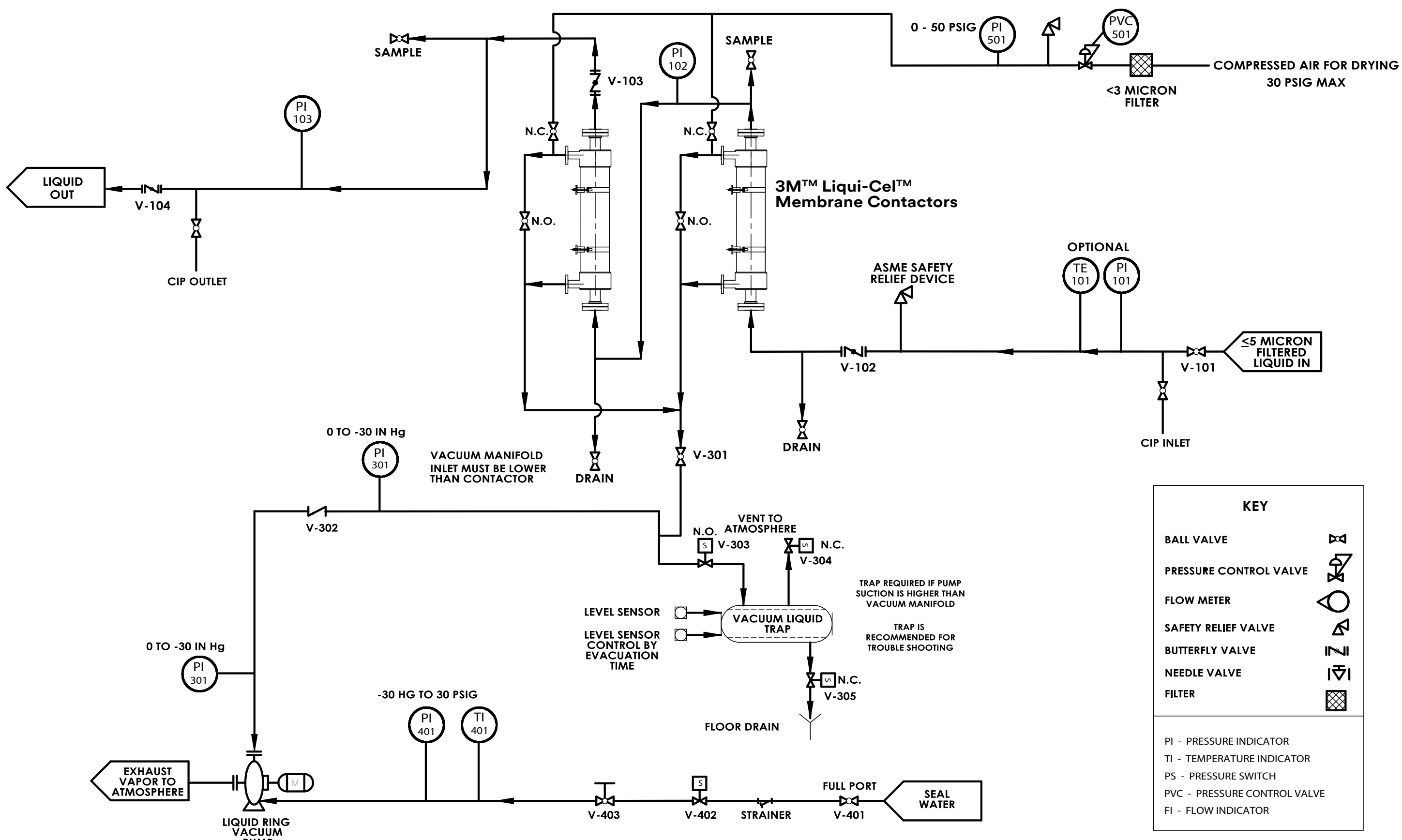
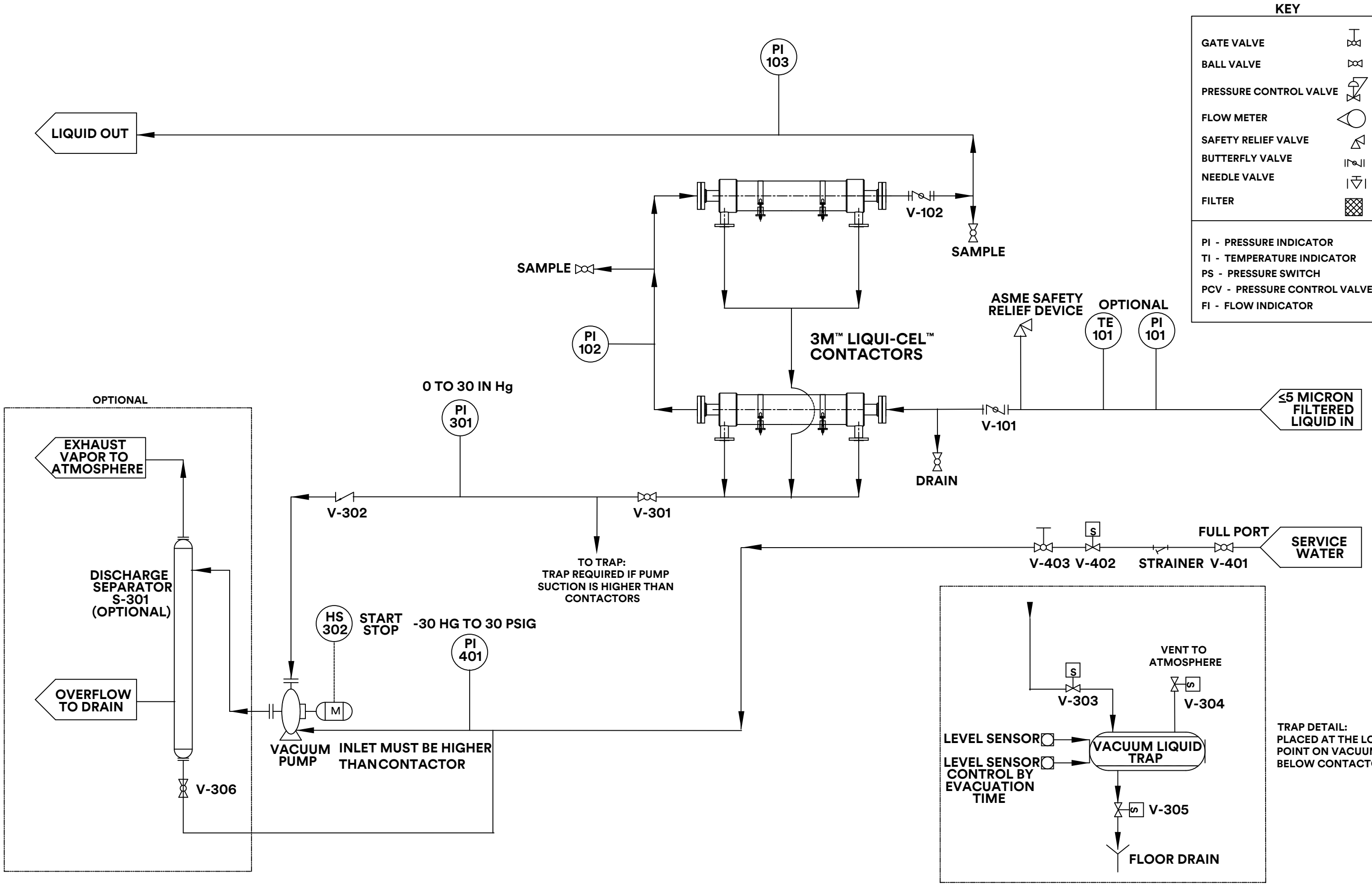


Figure 8. Generic P&ID for Vacuum Mode Operation with Two Membrane Contactors in Series: Horizontal Mounting



C. Sweep-Assisted Vacuum (COMBO)

Operation Note: Sweep-assisted vacuum is the most efficient way to achieve low levels of dissolved O2 or low levels of CO2 in water.

In Combo Mode a sweep gas is introduced to one lumen port of the membrane contactor, while the other lumen port is connected to a vacuum source. The sweep gas helps move and dilute the gas that is in the vacuum stream. Typical recommended vacuum level is 24 to 28 inch Hg gauge, or 50 to 150 mm Hg (67 to 200 mbar) absolute at sea level. The vacuum level for water < 20 °C is typically 50 torr (67 mbar) and is increased as the water temperature is increased. This is done to reduce the vacuum pump size since the amount of water vapor at 35 °C is much higher than at 20 °C.

Sweep gas and Vacuum side Configuration and Operation

Sweep gas configuration:

1. Recommended instrumentation in Combo mode (see Figures 9 and 10)
2. Pressure regulator valve (PCV-201), required only when using compressed gas as sweep
3. Needle valve (V-202)
4. Pressure gauge (PI 201), required only when using compressed gas as sweep
5. Flowmeter (FI-201). Use a flow meter calibrated at the set gas pressure (Nm3/h or scfm)
6. For CO2 removal, compressed air or nitrogen can be used as sweep gas.

For oxygen removal, the sweep gas can be an inert gas (CO2 or N2) with a purity of at least >99.9%.

> If using compressed dry air, make sure that it is oil-free. A 0.2-micron filter is highly recommended for high purity applications. A 1- 3-micron filter rating is enough for industrial applications.

The needle valve (V-202) is installed on the sweep gas inlet line between the membrane contactor and the gas flowmeter. This allows the flowmeter to operate under a positive pressure thus eliminating possible air leaks into the gas line through the flowmeter. Rotameters MUST be used with a downstream needle valve if the flow control valve is before the float. Some rotameters place the flow control valve downstream of the float indicator (at the rotameter outlet line) and that type is suitable. Mass flowmeters are not affected by inlet gas pressures.
Note: For CO2 removal, a blower in suction mode can be used to pull room air into the membrane contactors. See section D below for more details. If room air is used, PCV-201 is not needed.

Vacuum Side:
Recommended instrumentation to operate in Combo mode:

- Pressure indicator (PI-301) for vacuum application
- Check valve (V-302)
- Vacuum Liquid Trap (optional, system configuration may not require a liquid trap)

Successful operation of a 3M™ Liqui-Cel™ Membrane Contactor system in vacuum or combo mode depends on a well-designed gas line and vacuum system (piping and vacuum pump). It is important to follow these recommendations when designing a vacuum system:

Piping

- Design the vacuum line piping size for vacuum service. Threads, pipe dope, and pipe tape should be used with extreme caution to prevent air leaking into vacuum line. Any air leaks will negatively impact the degassing efficiency.
- The minimum vacuum pipe diameter should equal the vacuum pump inlet connection size.
- Avoid long runs of piping and loops. Minimize the use of elbows and other sources of pressure loss.
- Design the vacuum manifold to handle the vapor load of the entire system. Since water vapor and other volatile gases will pass through the membrane, the lumen side gas will become saturated with the water vapor. Depending on the temperature, condensation could occur in the outlet gas piping. Therefore, the outlet piping should be sloped down and away from the membrane contactors to allow this water to drain from the membrane contactors and out of the piping. If water vapor condensate is not removed, it can collect over time and possibly reduce the performance of the vacuum pump, which will affect the performance of the membrane contactors. The condensation rate depends on the liquid temperature. The warmer the liquid stream, the higher the water-vapor transport rate. This condensation phenomenon is normal. Purging the lumen with sweep gas or air at high flow rate for 5-30 minutes will facilitate clearing water vapor out of the lumen.
- Additionally, when operating in sweep or combo mode with low flow rates in smaller membrane contactors (8-inch or smaller), we recommend vertically mounting the membrane contactors with water flowing from bottom to top and sweep flowing from top to bottom. The downward sweep used in vertically mounted membrane contactors facilitates keeping the lumens purged of condensation.
- If possible, use a short section of transparent PVC pipe to monitor water flow into the vacuum pump. This will aid greatly in troubleshooting a leaking membrane contactor.

Vacuum Pump Type and Sizing

- Utilize the sizing program or contact a 3M representative to estimate the vapor load to the vacuum pump expressed in actual ft^3/min (ACFM) or m^3/hr. The vapor load value and the vacuum level will determine the size of the vacuum pump.
- A liquid ring pump is recommended. There are many brands of liquid ring pumps; choose the one that satisfies your needs and ask your supplier for a complete vacuum system, which includes: a vacuum pump, liquid trap, check valve, air bleed valve, gauges and a separate seal water line.

For Safety and Protecting equipment

In the rare event of a major membrane failure and resulting water bypass to the vacuum pump in vacuum or combo mode, a liquid trap and a high vacuum pressure switch are recommended for the vacuum line. A low-pressure alarm switch or a flow switch located in the water outlet of the membrane contactor; it is recommended to prevent the pump or other major equipment from running dry.

Figure 9. Generic P&ID for Sweep-assisted Vacuum (Combo) Operation with Two Membrane Contactors in Series: Vertical Mounting (SMC-0113-10-5749)

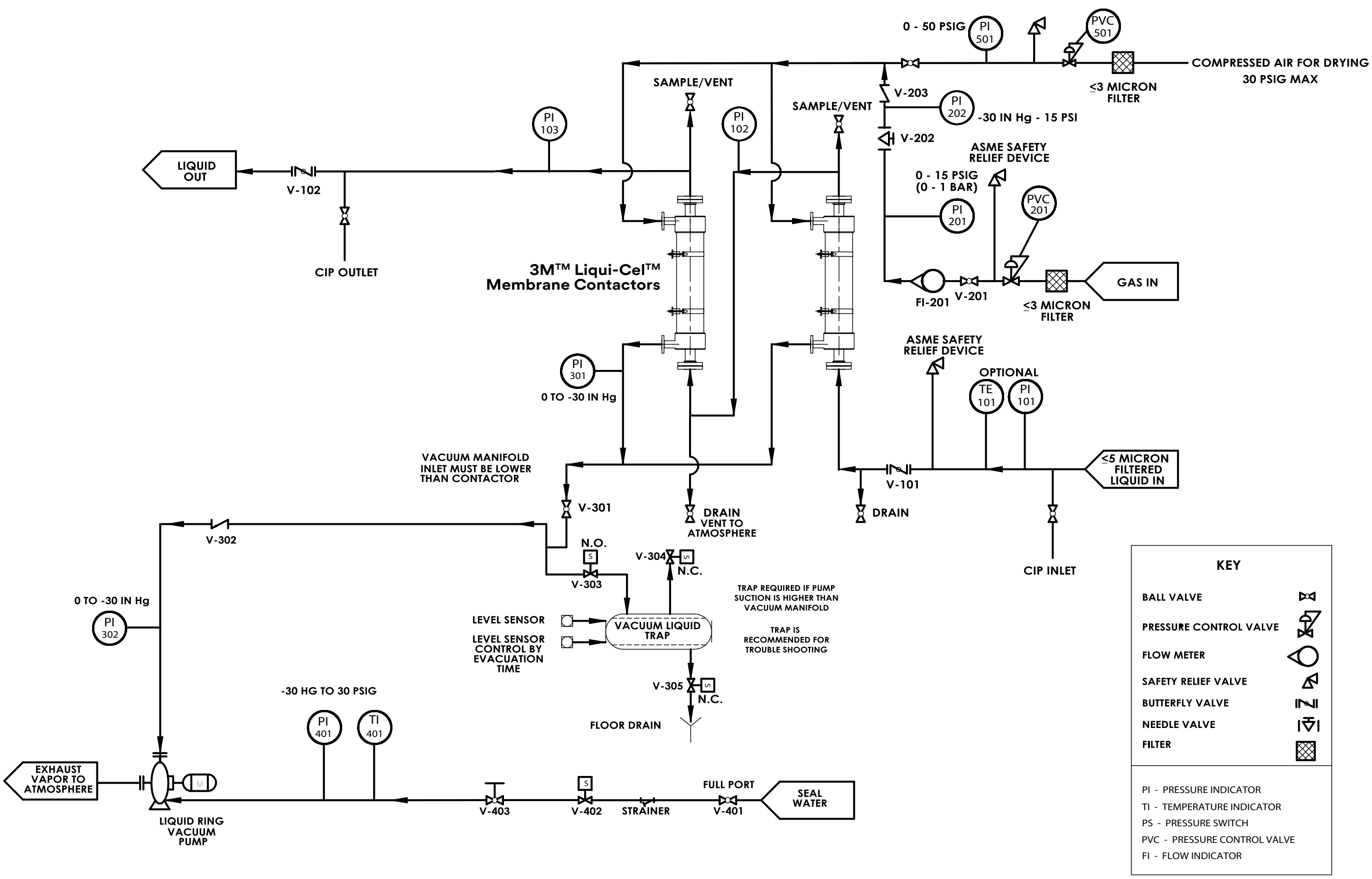


Figure 10. Generic P&ID for Sweep-assisted Vacuum (Combo) Operation with Two Membrane Contactors in Series: Horizontal Mounting (SMC-0113-10-5750)

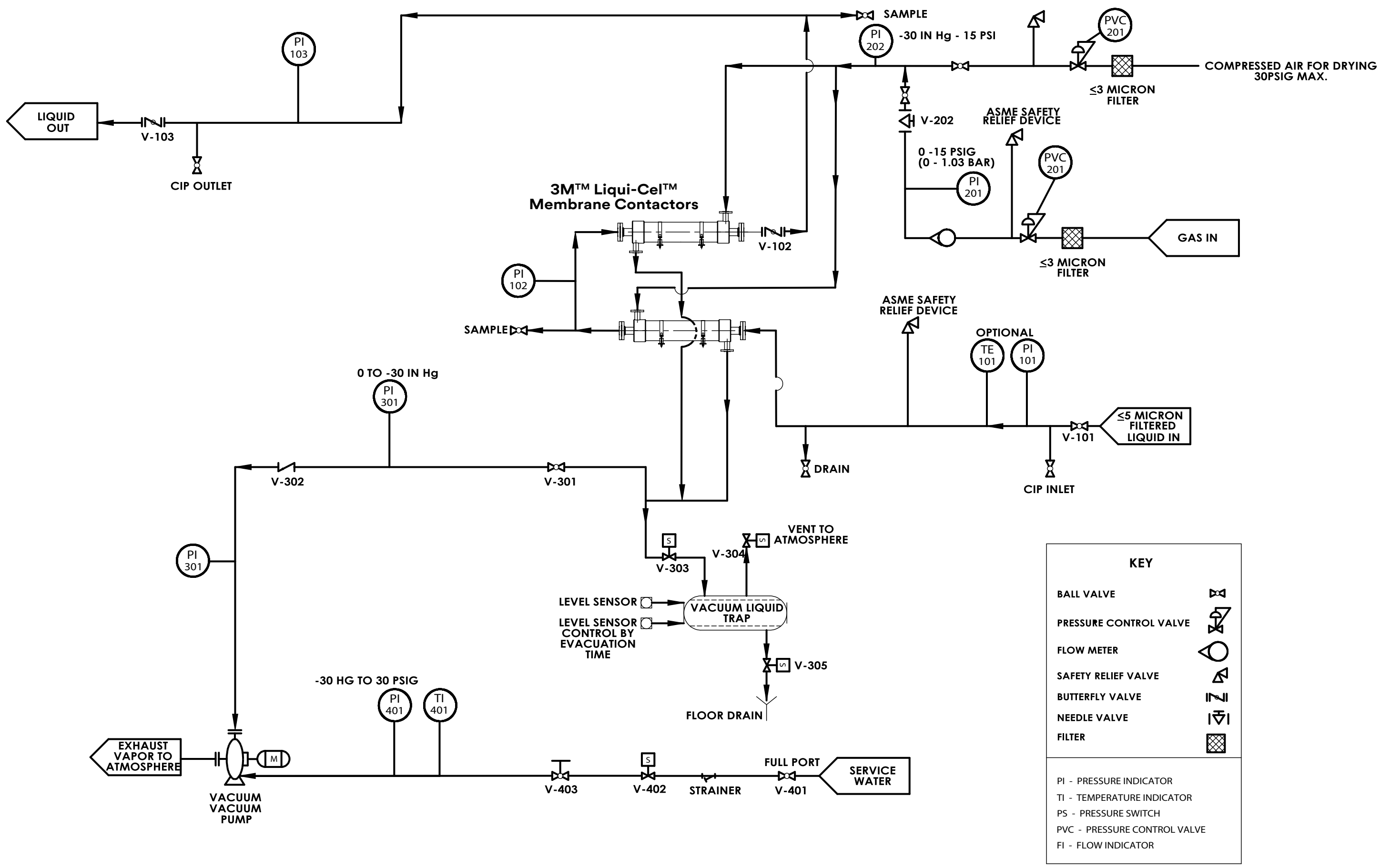


Table 5: Typical Recommended Sweep Flow Rates for Combo Mode of Operation

3M™ Liqui-Cel™ Membrane Contactor	Air Sweep in Combo Mode		N2 Sweep in Combo Mode	
	SCFM	Nm3/hr	SCFM	Nm3/hr
2.5×8	0.05 - 0.25	0.08 - 0.4	0.02 - 0.1	0.03 - 0.2
4×13	0.2 - 1.0	0.3 - 1.6	0.1 - 0.5	0.16 - 0.8
4×28	0.2 - 2.0	0.3 - 3	0.1 - 1.0	0.16 - 1.6
6×28	0.4 - 2.0	0.7 - 3	0.2 - 1.0	0.3 - 1.6
8×20	0.5 - 5.0	0.8 - 8	0.2 - 1.0	0.3 - 1.6
8×40	1 - 5	1.6 - 8	0.4 - 1.0	0.6 - 1.6
8×80	Not Recommended for Combo Mode		0.5 - 1.0	0.8 - 1.6
10×28	2 - 10	3.2 - 16	0.4 - 1.0	0.6 - 1.6
14×28	3 - 15	4.7 - 24	0.5 - 1.0	0.8 - 1.6
14×40	Not Recommended for Combo Mode		0.5 - 1.0	0.8 - 1.6

D. Blower in Suction Mode (Induced Draft Blower) for CO2 Removal - Configuration and Operation

Using a blower in suction mode to pull in atmospheric air through the lumen side of the membrane contactor is a lower cost alternative to using compressed air for carbon dioxide removal. However, it is critical that blower exhaust is discharged away from the air intake ports of the membrane contactors to prevent CO2 in blower exhaust from being pulled back into the membrane contactor. Dissolved CO2 levels down to 2-5 ppm can be achieved using Blower method. To achieve lower levels of CO2 (<1 ppm) combo mode described in previous section must be used.

Gas Side: Recommended instrumentation to operate using a blower in suction mode (see Figures 11 and 12):

- Needle valve (V-201)
- Flowmeter (FI-201)
- Liquid trap in suction pipe to protect blower from liquid
- Air filter, preferably < 3-micron rating

Liquid Side: Recommended instrumentation (Figures 11 and 12):

- Pressure indicator inlet/outlet
- Isolation valves
- Sample valves
- Drain valves

Successful operation of a 3M Liqui-Cel Membrane Contactor degasification system depends upon a well-designed system. It is important to follow these recommendations when designing a system using a blower in suction mode:

Piping

- Avoid long runs of piping and loops. Minimize the use of elbows and other sources of pressure loss.
- Protecting the blower – there will be water vapor transport from the liquid side of the membrane to the gas side of the membrane. Installing a clear liquid separator with a drain is recommended between the gas outlet of the membrane contactors and the blower suction port to protect the blower from premature failure due to water vapor impacting the blower.
- The exhaust temperature of a regenerative type of blower can burn a person or melt certain plastic pipe. Always use exhaust piping capable of handling the exhaust temperature.

⚠ **To reduce the risks of asphyxiation [or other health hazards], accidental gas ignition (combustion), or environmental contamination**.

- Ensure proper system ventilation and discharge of any gases being used in membrane contactor operation, including sweep gas, vacuum pump or blower discharge, according to all applicable building codes and regulations.

Blower Type and Sizing

- Utilize the sizing program or contact your local 3M representative to estimate the air sweep flow rate needed in cfm or m3/hr, and the air pressure drop in membrane contactor in mbar (relative) or inch of Water Column (WC). These two parameters will determine the size of the blower.
- A regenerative type of blower is recommended. There are many brands of blowers; choose the one that is appropriate for the intended application.

Table 6: Recommended Sweep Flow Range for Operating with a Blower in Suction Mode

3M™ Liqui-Cel™ Membrane Contactor		
	SCFM	Nm^3/hr
2.5×8	0.25 - 1.5	0.4 - 2.4
4×13	1 - 6	1.6 - 9.5
4×28	1 - 10	1.6 - 15.8
6×28	2 - 12	3.2 - 19
8×20	3 - 18	4.7 - 28.5
8×40	5 - 20	7.9 - 31.7
8×80	Not Recommended for Air Sweep Mode	
10×28	5 - 30	7.9 - 47.5
14×28	10 - 60	15.8 - 95
14×40	Not Recommended for Air Sweep Mode	

Figure 11. Generic P&ID for Using Blower to Pull in Atmospheric Air, Two Membrane Contactors in Series: Vertical Mounting (SMC-0108-10-7097)

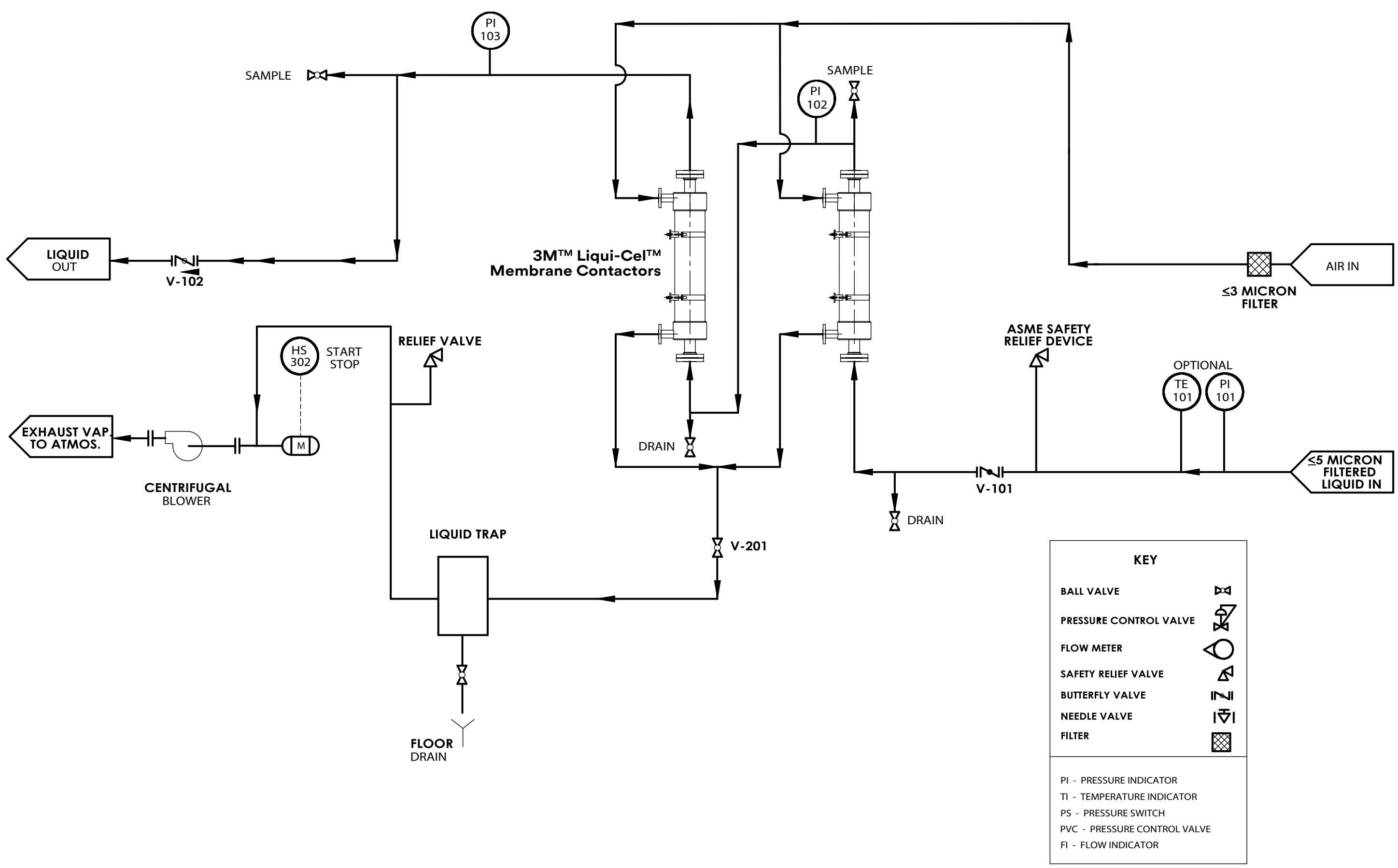
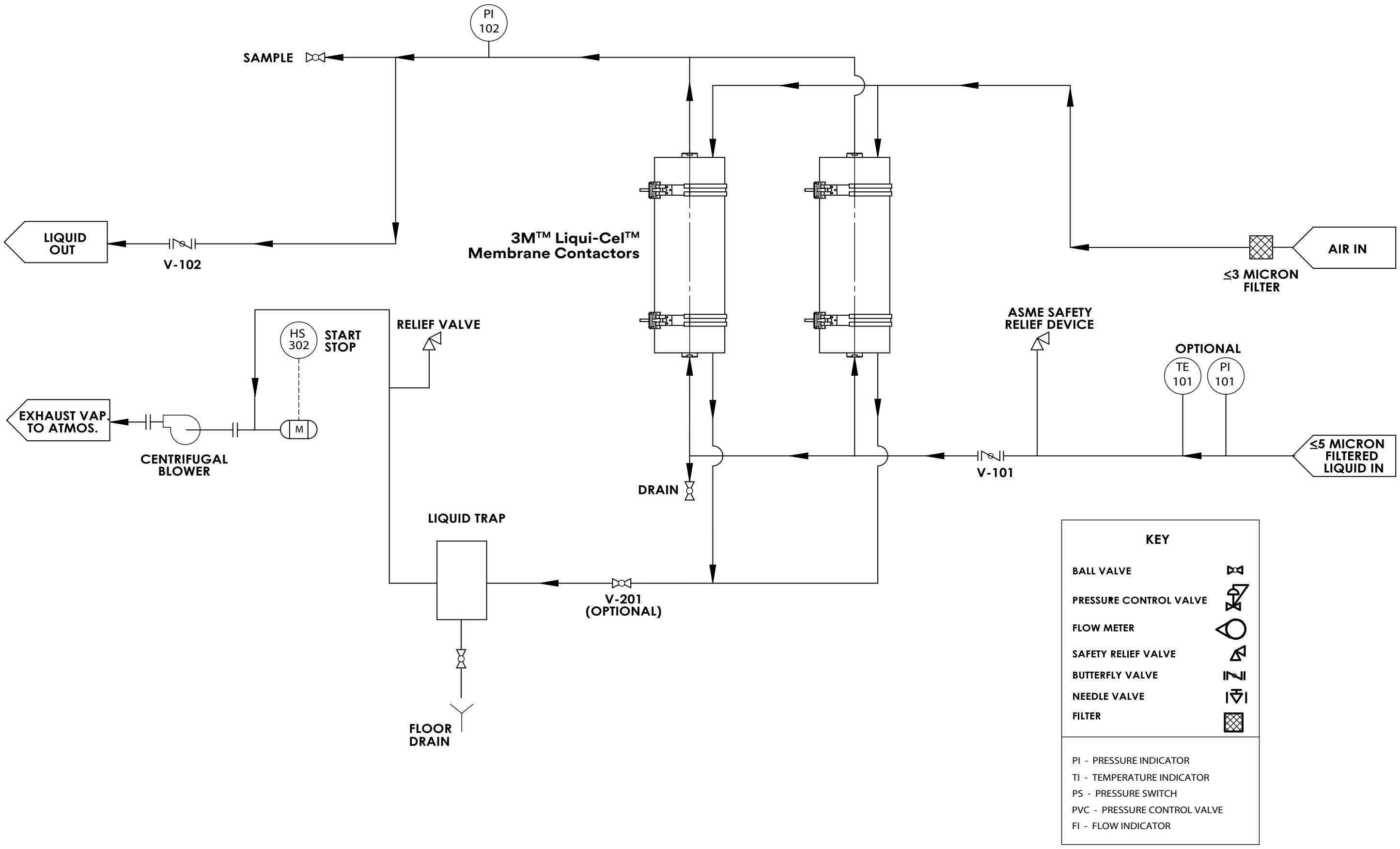


Figure 12. Generic P&ID for Using Blower to Pull in Atmospheric Air, Two Membrane Contactors in Parallel: Vertical Orientation (SMC-0108-10-9170)



V. <u>General System Design Guidelines</u>

A. Flow Pattern Configurations

Determination of Series and Parallel Configuration

Each type of 3M™ Liqui-Cel™ Membrane Contactor has a recommended minimum / maximum water flow rate. For system flow rates that exceed the individual membrane contactor's maximum flow rate, it is necessary to split the flow into parallel trains. To determine the <u>minimum</u> number of parallel trains, divide the total system water flow rate by the maximum flow rate provided in Table 7. The actual number of parallel trains and membrane contactors in series is determined by the required gas removal performance and liquid pressure drop.

The minimum flow rates listed on the data sheets and in Table 7 are guidelines. 3M Liqui-Cel Membrane Contactors could be used below the listed flow rate, but 3M cannot make a performance sizing below the listed flow rate guideline.

Table 7: Recommended Minimum and Maximum Water Flow Rate in Individual Contactors

3M Liqui-Cel Membrane Contactor	Water Flow Rate per Contactor	
	gallons/min (gpm)	m^3/hr
2.5×8 EXF	0.5 - 3.0	0.1 - 0.7
2.5×8 SP	0.5 - 3.0	0.1 - 0.7
4×13 EXF	2 – 15	0.5 – 3.4
4×13 SP	1 – 15	0.2 – 3.4
4×28 EXF	4 – 30	0.9 – 6.8
4×28 SP	5 – 30	1.1 – 6.8
6×28 EXF	5 – 50	1 - 11
8×20 EXF or IND	5 – 50	1 - 11
8×40 EXF	25 – 70	5.7 – 15.9
8×80 EXF	25 – 70	5.7 – 15.9
10×28 EXF	44 – 250	10 - 57
10×28 IND	44 – 210	10 - 48
14×28 EXF	70 – 400	16 - 91
14×40 EXF	70 – 550	16 - 125

After calculating the minimum number of parallel trains, additional membrane contactors can be added in series to obtain the desired dissolved gas concentration at system outlet. The number of membrane contactors in series will be a function of the required gas outlet and the maximum allowable system pressure drop specified by customer. Typically, five membrane contactors in series is the maximum. Performance is also improved with lower water flow rates. If the maximum allowed system water pressure drop is reached, one can also add additional parallel trains of membrane contactors to achieve lower gas outlets and lower pressure drop.

Liquid-Stream Flow Configuration
The following are guidelines for designing the water process lines for a 3M Liqui-Cel EXF Series Membrane Contactor system. These guidelines take into consideration the membrane contactor orientation. While liquids typically flow on the shell side of the contactor, some applications utilize lumen side liquid flow.

B. Vertical or Horizontal Mounting

- If the water pressure coming into the 3M Liqui-Cel Membrane Contactor system is greater than the maximum operating pressure, a pressure regulator is strongly recommended. For maximum pressure ratings and maximum operating temperature refer to the appropriate data sheet or Section IV C below.
- To avoid damage from water hammer, always use slow closing valves on the downstream side of the membrane contactor system.
- Water side low-point drains, pressure indicators and temperature indicators should be included in the design.
- Gas flow must be countercurrent to liquid flow for all membrane contactors in the system. If not, lower gas removal efficiencies will result.
- The membrane contactors can operate when the air temperature is below freezing only when the water is flowing through the shell side. During shutdowns, the membrane contactors must be protected from freezing temperatures. Protection options include placing system in a heated environment or electric heat line tracing.
- If a wet system (after draining) is transported by airfreight or by truck during freezing temperatures, it is necessary to dry the membrane contactors prior to shipment. Refer to the 3M Liqui-Cel Membrane Contactor Cleaning and Storage Guidelines.

Vertical Mounting:

- The preferred mounting orientation is vertical.
- If the membrane contactors will not be used continuously, vertical mounting is strongly recommended.
- The bottom gas port should be located higher than the suction port of the vacuum pump. This will allow for free drainage of condensed water to the vacuum pump (Figures 13 and 14). If the vacuum manifold cannot be sloped continuously, install a vacuum liquid trap at the lowest point.

Figure 13: Vertical Mounting - Vacuum Mode

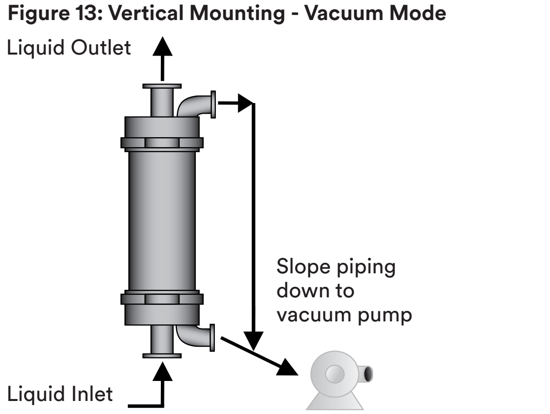
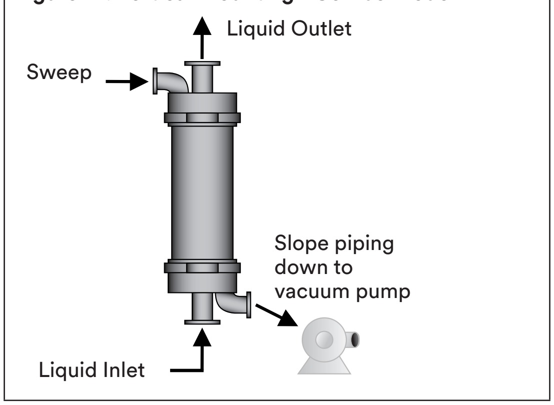
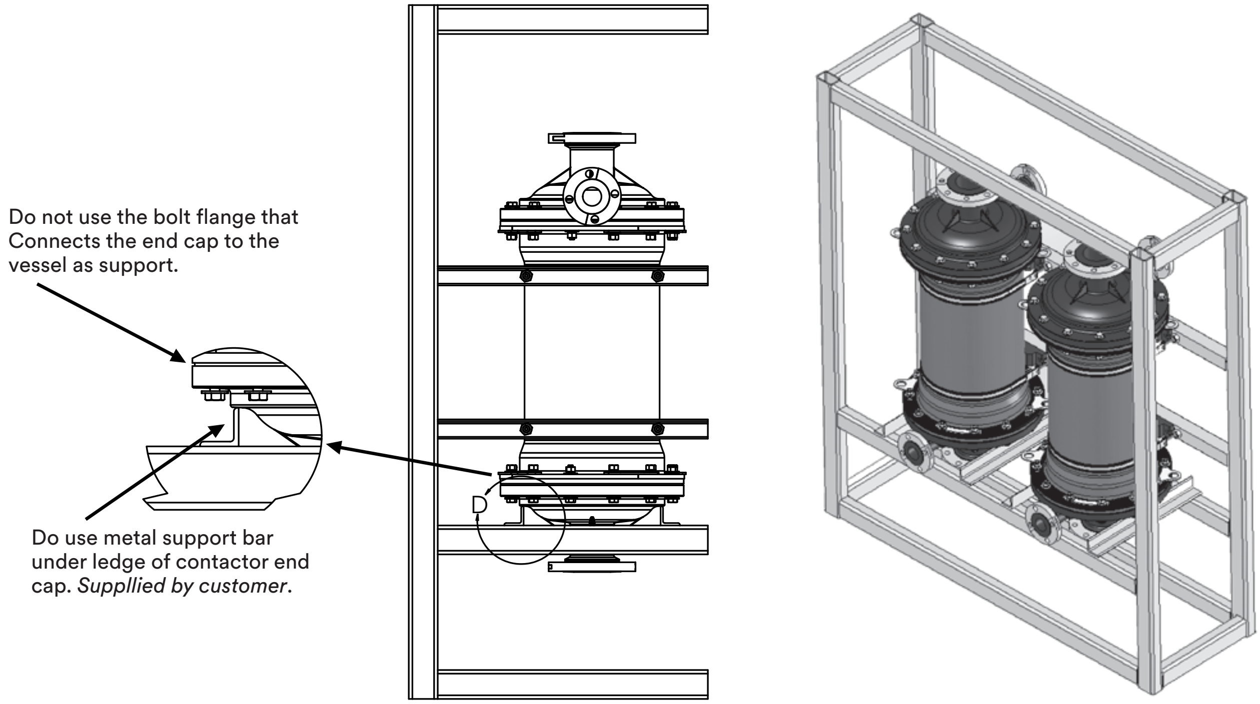


Figure 14: Vertical Mounting - Combo Mode



Additional Information for Vertically Mounting 14×28 and 14×40 Membrane Contactors
It is recommend using 3M mounting kits and an additional steel bar support under the membrane contactors to adequately support the full weight of the 14×28 and 14×40 membrane contactors. Do not place the membrane contactor load on the bolt flange that is used to secure the end caps onto the housing. Also, do not place the membrane contactor load on the piping materials. Please refer to the 14×28 and 14×40 vertical skid mounting drawings on 3M.com/Liqui-Cel. These will provide you will more detailed information. A basic view of the metal support that is located under the bottom end caps is depicted in Figure 15 below.

Figure 15: Supporting 14×28 and 14×40 Membrane Contactors When Mounted Vertically



Horizontal Mounting:

- If the membrane contactors will be used continuously, horizontal mounting can be used.
- *For vacuum only operation*, the gas ports should be oriented downward with the gas ports located higher than the inlet port of the vacuum pump. See Figure 16.
- Horizontal mounting in sweep or sweep gas assisted vacuum (combo) mode as shown in Figure 17, with gas ports rotated 180 degrees, can be used for large membrane contactors for ease of installation and replacement. For smaller membrane contactors or smaller water flow rates vertical mounting is recommend with liquid flowing upward and gas flowing downward. Vertical mounting facilitates draining of fibers under gravity and helps to reduce liquid buildup on the lumen side. The recommendation for vertical mounting is particularly important if the sweep gas flow rate is low.

Figure 16: Horizontal Mounting - Vacuum Mode

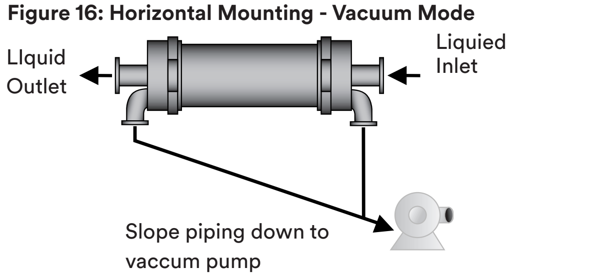
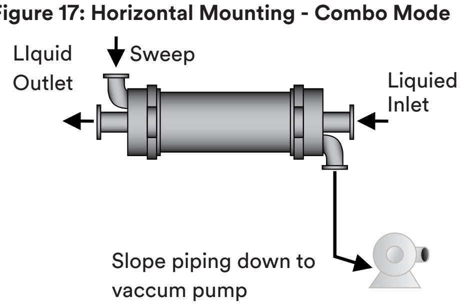


Figure 17: Horizontal Mounting - Combo Mode



- *For combo or sweep mode operation*, the gas ports should be oriented 180° in relation to each other, and the vacuum side or gas exit should be pointing downward. The gas port exit should be higher than the inlet port of the vacuum pump to facilitate water drainage into the vacuum pump. If the vacuum manifold cannot be sloped continuously, install a vacuum liquid trap at the lowest point. See Figure 17.

Important Notes:
For EXF-8×80 series membrane contactors only - It is recommended that both ends of the membrane contactor are accessible to allow for cartridge change-out.

C. Maximum Operating Temperature and Pressure Guideline

Please refer to the latest data sheet found at: https://www.3m.com/3M/en_US/liquicel-us/resources/data-sheets/

D. Membrane Contactor Weights for System Fabrication

Please refer to the latest data sheet found at: https://www.3m.com/3M/en_US/liquicel-us/resources/data-sheets/

E. Filtration Requirements

The inlet liquid and gas streams need to be pre-filtered. The proper filtration arrangement depends on the water source so a comprehensive water quality analysis should be completed. Changes in water quality, such as seasonal variation, should be taken into consideration. The optimal filtration and pre-treatment arrangement will depend on several variables, including the water source, operating conditions, biological matter, organics, Total Dissolved Solids (TDS) and other factors. A small filtration pilot system can reveal valuable information to be used to design the final pre-filtration system. 3M produces a complete line of filtration products, contact your local 3M sales representative for further details.

Table 8 provides the minimum recommended filtration guidelines to prevent potential membrane fouling and blockage due to particles which will create a high pressure drop across the membrane contactors and restrict the flow through the membrane contactor system. Additionally, some dissolved compounds found in well, surface and city water will pass through the pre-filter and could potentially deposit on membrane's surface. Particularly, agglomeration or precipitation of certain dissolved compounds could occur with pH changes. To prevent blocking or precipitation, it is recommended to use a water softener or cation exchanger followed by 5 µm absolute pre-filter as a minimum requirement.
The potential for a pH shift caused by the removal or addition of certain gases, such a CO2, may either help prevent fouling of the membrane surface or may cause scaling. Consult your water treatment specialist to answer these questions.

Table 8: Sweep Gas and Water Inlet Quality Guidelines

Sweep Gas (lumen side) inlet pre-filter Must be oil- and aerosol-free	0.2 µm absolute rating for high-purity applications; 1-3 µm absolute rating for industrial applications			
Inlet Water (shell side) Quality Indicator	**Units**	**Recommended Level**	**Prevention / Control**	**Membrane Cleaning**
Turbidity	NTU	<0.5	flocculation/ UF/NF/RO	no treatment
Colloids	Silt Density Index (SDI)	< 3	flocculation/ UF/NF/RO	no treatment
Total Suspended Solids	ppm (mg/l)	<5 mg/L	flocculation/ UF/NF/RO	no treatment
Particle Size	Micron, absolute rating [1]	≤5 for typical particles	Pre-filtration	Back washing (not for carbon black fines)
		<1 downstream of carbon beds		
Dissolved Organic Carbon	ppm	< 5	UF/RO	(hot) caustic
Suspended Oil	ppm	≤ 10	filtration	(hot) caustic
pH	units	0.5 - 14		-
Silica – Colloidal	ppm	<10	antiscalants	hot caustic
Surfactants	ppm	0		50/50 water/alcohol cleaning & drying
Total Hardness [2]/Langelier Saturation Index (LSI)	ppm/Langelier Saturation Index	10 ppm	softening/antiscalants	Acid cleaning
		≤ 0 LSI		

[1] Do not use Nominal rated filters, only Absolute rated filtered, recommended 99.9% particle removal efficiency (Beta 1000).

[2] Total Hardness along with LSI is needed to predict if the water will scale. Total Hardness alone is not enough.

F. Membrane Fouling and Scaling

When a 3M™ Liqui-Cel™ Membrane Contactor system is used to remove CO2 from a water stream, watch for changes in water pH. Water may contain species that are soluble in water in acidic pH ranges but insoluble in alkaline pH ranges. If water pH increases as the water passes through the membrane contactor (this happens when dissolved CO2 is removed from water) the insoluble species might precipitate on the membrane surface. Precipitation of solids can also occur when water is treated with flocculation chemicals followed by a change in pH. For example, alum (aluminum sulfate) is often used to remove suspended matter from water. The removal takes place by coagulation, flocculation and precipitation in the water clarifier tank. The precipitation occurs in the form of polymeric aluminum hydroxide at certain pH ranges. As CO2 is removed from the feed water, a change in pH may be enough to precipitate excess aluminum hydroxide or other compounds on the membrane's surface. The thin coating or deposits will prevent normal gas transfer through the membrane and the membrane contactor's removal efficiency will drop. This process is reversible by cleaning the membrane contactor with an acid solution such as 3% w/w ortho-phosphoric acid solution (refer to the 3M Liqui-Cel Membrane Contactor Cleaning and Storage Guidelines). The acid solution may dissolve surface precipitates on membrane and will restore the contactor degassing performance to original manufacturer's specifications.

When the contactors are installed downstream from carbon beds, a 1-micron absolute filter should be installed, and the carbon beds should be flushed to drain after the carbon change-out until all carbon fines are flushed out. Care should also be taken when back flushing carbon beds that are downstream of membrane contactors. Filtration should be added to keep the contactors free from carbon particles, which can be difficult or impossible to clean.

When Membrane Contactors are installed upstream of RO membranes, a cleaning cycle is also recommended in order to prevent fouling. Please refer to the 3M Liqui-Cel Membrane Contactor Cleaning and Storage Guidelines available on-line at 3M.com/Liqui-Cel or from your 3M representative.

VI. Startup, Shutdown and Downtime Procedures

A. General startup instructions for the liquid phase

Note: Both gas/vacuum ports should be open during operation. These ports provide a safety vent in the membrane contactors so that pressure does not build up.

1. Slowly introduce water to the system, making sure that water inlet pressure and water flow rate through the membrane contactor never exceed the maximum operating limits
2. Adjust water flow rate and inlet pressure to the desired levels by adjusting the appropriate valves on the system.

B. Startup Instructions for strip gas or vacuum mode

Note: Vacuum should always be pulled from the lowest gas port to facilitate draining and ensure performance.

Sweep Gas Only Mode
To operate the system, follow these steps, referring to Figure 5 or 6.

1. Fill shell side with water by closing V102 and open V101.
2. Set the initial sweep gas pressure up to to 1 barg (15 psig) by adjusting PCV-201.
   Note: Liquid pressure should always exceed gas pressure inside the membrane contactor but below the maximum allowable vessel pressure see section IV C. If gas pressure is above liquid pressure, the gas will pass into the liquid side. This can occur when the liquid flow stops and its pressure falls below the gas pressure.
3. Set the recommended total sweep flow rate (listed in Table 4 by adjusting the V-201 valve and the reading on the FI-201 flowmeter. If the sweep gas rate is too low, then slowly raise the pressure using the gas regulator. Raise the sweep gas pressure to the lowest pressure to obtain the necessary sweep gas flow rate. Refer to the manufacture's flow corrections when using a gas inlet pressure > 0 bar (0 psig)
4. Slowly open water outlet valve, V102.

If using compressed dry air, make sure that it is oil-free. A 0.2-micron filter is highly recommended for high purity applications. A 1- 3-micron filter rating is enough for industrial applications.

If compressed gases or oil-free compressed air are not available, for CO_2 removal; a blower may be used in suction mode to create an air sweep flow in membrane contactor. 3M can calculate the pressure drop on the gas side, use this information to choose the blower size.

NOTE: If water vapor condensation occurs on the gas side during a system shutdown, it is recommended that the gas side be purged with sweep gas or air at high flow rate for about 5-30 minutes during re-start of system. During this purge, water inlet and outlet ports should be closed to prevent the purge gas escaping through liquid in/out ports. Purging will clear all condensed liquid from the lumen side and will allow the system to achieve expected performance.

Vacuum Only Mode
To operate the system, follow these steps, referring to figure 7 or 8. Refer to the vacuum pump manufacturer's instructions for startup.

1. Open the vacuum manifold valve, V-301
2. Fill shell side with water by closing V104 (V102 figure 8) and open V101.
3. Turn on the vacuum pump.
4. Slowly open water outlet valve, V104 (V102 figure 8).

Sweep Gas with Vacuum (Combo) Mode
To operate in combo mode, follow these steps, referring to figure 9 or 10.

1. Open the vacuum manifold valve, V-301
2. Fill shell side with water by closing V102 and open V101.
3. Turn on the vacuum pump.
4. Regulate sweep gas supply pressure up to 1 barg (15 psi), by adjusting PCV-201. **Use lowest pressure for the gas sweep rate desired. Refer to the manufacture's flow correction factors when using a gas inlet pressure > 0 bar (0 psig)**
5. Set the recommended total sweep gas flow rate by adjusting the V-201 (V202 figure 10) valve and the reading on the FI-201 flowmeter. See Table 5.
6. Slowly open water outlet valve, V102 (V103 figure 10).

See sweep guidelines for typical sweep gas flow rate ranges in Table 5.
Note: If water vapor condensation occurs on the gas side during a shutdown period, we recommend following the same purge procedure as elaborated in the section above.

Blower in Suction Mode with atmospheric air as sweep gas for CO_2 removal
To operate blower in suction mode, follow these steps, refer to figure 11 or 12.

1. Fill shell side with water by closing V102 and open V101.
2. Turn on blower
3. Check the air flow (FI-201) according to Table 6.
4. Open water outlet valve, V102

C. Shutdown Procedure

1. Close gas inlet valve (if applicable).
2. Shutdown vacuum pump or blower (if either are applicable).
3. Slowly close the water inlet valves first, allow shell side to be depressurized, and then close the water outlet valves. If possible, drain all liquid from the membrane contactor after shutdown. Open vacuum manifold valve to assist draining. If the system will be standby mode for longer than 3 days, see section E, Downtime Guidelines, below.

D. Startup after a Shutdown

Startup described in the previous sections.

Note: when startup occurs after a shutdown period, water may have condensed inside hollow fibers and should be removed during the normal startup. It may take up to several minutes for the oxygen outlet levels to return to their pre-shutdown levels.

If the oxygen levels do not return to pre-shutdown levels, do the following: Connect oil-free, 3 µm filtered compressed air, N_2, or CO_2 to the vent valve and apply pressure through the vent valve at less than 2 bar (30 psi) to force out any water vapor that may have condensed inside the fiber lumens during the stand-by period. Continue gas flow for 10 minutes. Refer to figures 9 & 10 for drying line connections for combo mode. For vacuum only mode, start vacuum pump for 15 minutes without water running. If high oxygen levels still exist, use compressed air to blow-out condensate from fiber lumens – refer to figure 7 for vertical mounting. For horizontal mounting, insert a pipe tee in one of the vacuum legs and connect to a gas source. For blower systems, start blower for 1 hour without water flow. If high CO_2 levels exist after this step, use compressed air to blow-out condensate from fiber lumens. For sweep gas mode, increase the inlet gas pressure to < 2 bar and run for 15 minutes to remove condensate from fiber lumens.

E. Downtime Guidelines

The initial level of microbiological matter in the feedwater will determine how one should handle the membrane contactors for downtimes longer than 3 days. If there is little microbiological matter, such as with RO water, the approach is different than for raw filtered well water. The ambient air or water temperatures will also determine which protocol should be used. If membrane contactors are put into service and the system is idled or shut down for a period of time, follow these steps to minimize microbiological growth. In all cases, the membrane contactors must be stored above freezing.

There are four methods that can be used so it is important to known beforehand if the system will be operated on an intermittently basis. It is highly recommended that the system be designed specifically with intermittent operation in mind.

1. Circulation of water stream
2. Inert gas blanketing (easiest, need extra valve in vacuum manifold or exit valve in sweep gas only)
3. Biocide solution (extra chemical, tanks and pumps needed)
4. Drying - the most difficult to do in the field since blowers and high volumes of heated, dry clean air are needed. Not recommended for large installed systems beyond a lab-scale skid. Refer to the 3M™ Liqui-Cel™ Cleaning and Storage Guidelines for drying instructions for drying individual membrane contactors removed from a system.

Operating Mode	Short-Term Downtime (< 3 days)	Long-Term Shutdown (> 3 days)
Sweep Gas w/Vacuum (Combo)	Reduced waterside flow with slight lumen side gas purge, vacuum pump off	Inert Gas Blanket or Chemical Preservation
Sweep Gas Only	Reduced waterside flow with slight lumen side gas purge	Inert Gas Blanket or Chemical Preservation
Vacuum Only	Reduced waterside flow, vacuum pump off	Chemical Preservation or inert gas if available
Blower Suction	Reduced waterside flow, blower off	Chemical Preservation or inert gas if available

A conservative step would be to allow sweep gas to flow at a low rate to remove water condensate in the hollow fiber lumens. Keep in mind that once the vacuum pump is shutdown, air can leak past the check valve in the vacuum manifold and be in contact with the moist-laden lumens, increasing the tendency for bio growth in the gas-side. If there are frequent showdowns, example: every weekend, keep the inert sweep gas flowing at a reduced rate or store in inert gas.

Installation of a shut-off valve in the vacuum manifold allows the membranes to be preserved using an inert gas blanket or chemical solution during shut down.
Install drain valves between vertically mounted membrane contactors.

Shutdown < 3 days

If the system is shut down for short periods, typically for overnight or a weekend, contactors should be depressurized and water flow should be stopped, though contactors can remain water-filled. Gas or vacuum flow should continue during the shutdown period. If it is not possible to flow gas or vacuum, then close all valves during the shutdown period.

Shutdown > 3 days

If the system needs to be stopped for more than 3 days, and if contactors cannot be thoroughly dried, store the contactors with either an inert gas or a preservation liquid.

Inert gas blanket

a) Stop water flow, drain the water side if water has nutrients. If the water quality if RO quality, there is no need to drain the system.
b) Shut down vacuum pump (for vacuum combo mode) and close the gas inlet valve. (both modes)
c) Set inert gas pressure to 0.5 barg (7 psi).
d) Close gas exit (vacuum manifold or sweep gas outlet) valve.
e) Open gas side inlet valve and adjust pressure to 0.5 barg (7 psi)
f) To begin operations again, follow the normal startup guide

Chemical Preservation Liquid Method

Chemical Preservation Procedure

g) Stop water flow, drain the water side if water has nutrients. If the water quality if RO quality, there is no need to drain the system.
a) Shut down blower or vacuum pump
b) Flush system (if needed) with clean filtered (< 5um absolute, 99.9%) deionized or RO water.
c) Dilute caustic (pH 11.5 – 13) NaOH or KOH) solutions can be used to prevent biologic growth. An alternative is to use uncatalyzed ~1 wt % Sodium Metabisulfite (SMBS). Periodically monitor and maintain the solution concentration pH.
d) Fill system with shell side and lumen side with the chemical solution.
e) Close shell side and lumen side valves.
f) Once storage is finished, drain and flush with DI or RO water (or 5um absolute filtered water).
g) To begin operations again, follow the normal startup guide

NOTE Beverage Applications may follow this procedure: Shutdowns > 1 day: Drain the contactor system then conduct a Hot Water Sanitization – leave liquid full after the sanitization hold period (see Cleaning Guidelines). Then fill with 0.5 bar (7 psig) inert gas (CO_2 or N_2) on the lumen side. Close off gas inlet valve and monitor gas pressure.

Make up the solution using only De-ionized Water (DI) or Reverse Osmosis (RO) water, since using hard tap water may cause precipitation and possible mineral scaling and loss of performance. Do not use catalyzed bisulfite due to potential oxidation of the membrane. Other non-oxidizing biocides can be used such as Quaternary Ammonium, DBNPA, Glutaraldehyde, and Hydroxymethyl phosphonium sulfate. See the manufacturers data for suggested concentrations.

VII. Maintenance

Maintaining a system performance Log is recommended for 3M™ Liqui-Cel™ Membrane Contactors. Recording data is required to troubleshoot the system so a weekly or bi-weekly data log is required. The performance log should record critical information as shown in the example below. The data log is required to validate the system design and that the membrane contactors have been operated according to these guidelines.

Table 9: Typical Maintenance Log

Date	Operator	Water flow rate	Water and gas inlet temperatures	Vacuum level in contactor	Sweep gas flow rate in contactor	Inlet dissolved gas concentration	Outlet dissolved gas concentration

This log will show the user a pattern of consistent performance or a decline in performance over time. If the contactors are still performing to the stated performance, no maintenance is required. If a decline in performance is noted, it may be time to clean the membrane or purge the lumen side of the membrane contactors. Refer to the FAQ section of this manual for further details.

VIII. 3M Liqui-Cel Membrane Contactor Replacement Frequency Guidelines

The expected service life of 3M Liqui-Cel Membrane Contactors varies depending on many factors. It is important to note that membrane system designs can vary considerably. Membrane contactor lifetime can be affected by water quality, system performance specifications and operating conditions.

One must separate membrane failure and system performance issues before deciding when to replace membrane contactors. System design (i.e.- number of membrane contactors) is determined by the design engineer and depending upon the safety factor used. So, the number of contactors needed to meet system performance can vary. Therefore, the replacement time for each system design will vary since the system performance begins at different points. For example, a system designed with excess capacity may not be as sensitive to system performance degradation compared to systems designed without extra capacity.

Membrane contactor life is affected by water temperature, oxidation, particle and organic fouling (water quality) and frequency of cleaning.

Temperature
Recommended continuous operating temperatures for 3M Liqui-Cel Membrane Contactors typically range from 5-50 °C (41 – 122 °F) but refer to the data sheets for specific contactor details. 3M Liqui-Cel Membrane Contactors should not be operated below 1 °C (34 °F) due to risk of freezing. In some applications and certain membrane contactors can be operated continuously up to 60 °C (140 °F). Membrane contactors in stainless steel housings have higher temperature tolerances and can be hot water sanitized up to 85 °C (185 °F). Operating at higher temperatures may reduce membrane contactor service life: a membrane contactor in a system operating at 25 °C (77 °F) may last longer than in a system operating at 50 °C (122 °F). Exceeding the membrane contactor's temperature operating limit is likely to permanently damage the membrane contactor.

Membrane Oxidation
Oxidation is a complex process that is a function of the oxidizer chemistry and concentration, temperature, and concentration of dissolved metals. The hollow fiber membranes have various tolerances to oxidizing species, but the presence of oxidizers may reduce service life. Exposing the hollow fiber inside the membrane contactor to oxidizing species could cause hollow fiber degradation and/or modify properties of the hollow fiber surface. These changes may allow water to pass through the membrane, and in extreme cases, may make the hollow fiber brittle resulting in reduced system performance or even membrane contactor failure. The presence of a dissolved material, such soluble iron, could accelerate the oxidation reaction due to catalytic action.

Exposure to oxidizing species, such as free chlorine, UV radiation, chlorine dioxide, oxygen at high temperature in the feedwater will reduce service life. Refer to Table 8: Sweep Gas and Water Inlet Quality Guidelines.

Cleaning chemicals and hot water sanitization also reduce service life, see the 3M Liqui-Cel Membrane Contactor Cleaning and Storage Guidelines.

To help reduce risk of oxidation, it is recommended to minimize exposure to high water temperature, such as during hot water sanitization (HWS), or to high air temperature. Chemicals used for Clean-In-Place (CIP) processes should also be thoroughly reviewed to ensure the chemicals do not contain oxidizing species.

Particulate Fouling
Influent water to membrane contactors should be pre-filtered to remove insoluble particulates. The minimum pre-filtration requirement is 5-micron absolute at 99.9% removal efficiency. Insoluble particles can build-up over time and clog up the fluid flow channels inside the membrane contactors, increasing pressure drop. Insoluble or colloidal silica could cause increased pressure-drop. Refer to the Sweep Gas and Water Inlet Quality Guidelines

Biofouling or Organic Fouling
Biofouling inside the membrane contactor can occur if the influent water has high levels of Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Microbiological fouling can also occur if the system has long shutdown periods and is exposed to air via the vacuum header.

Organic compounds can also create fouling. For example, oils, dissolved polymers or proteins in beverage products or other natural compounds natural organic matter (NOM).

Frequency of Cleaning
A common question is "how often do I need to clean?". The answer is it depends on many factors. Water quality is the primary factor. Ultrapure water plants never have to clean since the water quality has no factors that cause fouling. Well water on the other hand, is prone to fouling due to the large variation of dissolved minerals and gases. City water lies in the middle region where it is good quality but based on the operation of the system, cleaning may now be needed. Plants that have weekend shutdowns can allow air to enter the system and allow bio-growth. That is why short-term downtime frequency should be designed into the system so inert gas or chemical storage steps can be designed into the operations.

Cleaning frequency and aggressiveness also have an impact on service life. Generally, the less cleaning, the longer is the service life. A cleaning protocol can only be designed once the system is operational and performance can be tracked over time. The cleaning frequency is to prevent the system performance from going out of specifications. Plotting gas removal over time will indicate when a cleaning should occur.

FAQ's concerning contactor/cartridge replacement

1. **What is the procedure to follow if I see system performance decline?**
   Compare the following parameters versus the original system design. 3M can evaluate the current operating conditions using the GasCad Sizing Program for 3M™ Liqui-Cel™ Membrane Contactors using the current conditions.

All these parameters should be compared to the original design.

- a significant change in water temperature of no more than 2°C lower than design
- vacuum level variation is no more than 20% above system design value (such as obtained from GasCAD)
- Nitrogen flow rate and purity are at design values
- Feed water flow rate is no more than 10% above design value

2. **What do I monitor to determine if cleaning or a replacement is necessary?**
Degassing performance should be based on monitoring of outlet dissolved gas concentration of the overall degas system, not on a single contactor performance efficiency (%), since system design is normally based on outlet gas concentration (i.e. - ppb). A reduction of 10% of a single contactor is not very relevant because the overall system efficiency and a single contactor efficiency behave very differently. A better way is to consider a 50% rise (e.g. - 10 ppb increases to 15 ppb) in system outlet dissolved gas concentration as a criterion.

3. **Is water side pressure-drop a good indicator for cleaning or replacement?**
3M does not recommend pressure-drop as the primary parameter for replacement because a change in pressure-drop, while it is easy to monitor, does not tell if degas system is meeting system performance. Higher system pressure-drop may or may not affect system performance, so setting a system pressure drop specification by itself does not help. However, pressure drop for cleaning is a suitable parameter – refer to the 3M Liqui-Cel Membrane Contactor Cleaning and Storage Guidelines for more details. Cleaning or replacement decisions are best determined from both (1) system-outlet dissolved gas levels, and (2) preferably, pressure drop in the leading (first) set of contactors of the system, rather than overall system pressure drop.

4. **How to monitor the water leak rate for membrane failures?**
The typical drip rate range was developed based on normally functioning contactors – see table 10 in the 3M Liqui-Cel Membrane Contactor Cleaning and Storage Guidelines. Even with higher than typical drip rates, the system may perform within specification.

   Replacement guideline should be based on change in oxygen performance, pressure drop and water drip rate. A higher drip rate should be taken into consideration while designing liquid trap in vacuum line (hold-up volume of trap and trap draining frequency).

5. **How to minimize the effects of oxidation?**
Refer to section III B of this guide.

6. **How to conduct a Contactor Sanitizing / Cleaning-in-Place?**
Refer to the 3M Liqui-Cel Membrane Contactor Cleaning and Storage Guidelines document available in the Resources Section on our website, 3M.com/Liqui-Cel, or from your 3M representative.

7. **How to check on Chemical Compatibility?**
For general guidelines, contact your 3M representative.

8. **How to perform a cartridge installation?**
Only applicable for membrane contactors designed for cartridge replacement (only stainless or high pressure FRP vessels).
For a detailed description, refer to the 3M Liqui-Cel Membrane Contactor Assembly and Disassembly Instructions available in the Resources Section on our website, 3M.com/Liqui-Cel, or from your 3M representative.

9. **What is the Plastic and FRP Vessel Operating Precautions?**
To maintain the service life of the FRP vessel, rate of temperature changes should be minimized. Preferably, heat-up and cool-down rates should not exceed 2 °C/minute (3.6 °F/minute).
To prevent premature failure of the PVDF, ABS and Nylon fittings, accurate alignment and proper support of those connections is critical. Pipe that is not properly supported will put additional stress on the plastic fittings, which can lead to a fitting failure. Use proper plastic pipe support guidelines when installing plastic vessels.
All contactors in plastic housings (except the 8×40 / 8×80) it is recommended not to use metal fittings. Misalignment of metal fittings/piping place a stress on the plastic ports and can crack the port flanges or distort the sealing surfaces.

IX. 3M™ Liqui-Cel™ Membrane Contactor Storage, Handling and Operating Environment

The Membrane Contactor can be damaged through improper handling and storage. After cleaning and complete drying of contactors, it is possible to store membrane contactors before using again. If drying is not completed, then contactors must be stored with preservatives. See section IV part E.

Container/packaging: If cleaning and drying are completed, 3M Liqui-Cel Membrane Contactors should be stored dry and in a sealed plastic bag or shrink wrap material to help prevent the introduction of contaminants into the contactor.

Temperature: 3M Liqui-Cel Membrane Contactors can be stored dry at temperatures < 50°C (122F), but preferably at lower temperature such as <35°C (95°F) to not risk reduced lifetime. Membrane contactors should always be stored above freezing temperatures, and if stored at low temperature, they should be allowed to equilibrate to room temperature before use.

Exposure to Sunlight: 3M Liqui-Cel Membrane Contactors should be stored in their original box, or other opaque box and should not be installed where they are exposed to direct sunlight.

⚠ **Storage and Handling:** Care must be taken not to drop, hit or impact the membrane contactor. Use appropriately rated lifting equipment for lifting or moving. Review the product data sheet or operating guide for weights at 3M.com/Liqui-Cel.

⚠ Store the membrane contactors in the horizontal position. 10×28-inch membrane contactors with stainless steel housings may be packaged in cardboard boxes or wooden crates. 14×28-inch, 10×28-inch with FRP housings, 8×20-inch and 6×28-inch membrane contactors are packaged in cardboard boxes. 8×40 inch and 8×80-inch membrane contactors are individually bagged, then cradled on pallets. Membrane contactors should be stored in a safe location where they are not at risk of falling, being crushed or impacted. Always ensure the membrane contactor, and any systems using membrane contactors, are stable, level, and properly secured. Be sure the membrane contactors/system cannot tip, roll, fall, slide or make any movement that may cause injury, damage to the unit, or damage to other system components.

IX. Troubleshooting

Various contactor performance problem descriptions, probable causes and suggested corrective actions are listed in Table 10.

Table 10: 3M™ Liqui-Cel™ Membrane Contactor Troubleshooting Guide

Problem Description	Probable Cause	Corrective Action
Outlet dissolved gas concentration above specification or generally low gas removal performance	Membrane contamination/fouling	Clean contactor. Refer to 3M Liqui-Cel Membrane Contactor Cleaning and Storage Guidelines.
	Dust covers used in shipping may not have been removed	Verify shipping dust plugs, cap covers, and/or shrink wrap are removed from all ports before installing the contactors into the system.
	Sweep gas contaminated	Verify sweep gas purity level.
	Insufficient sweep gas flow rate	Measure sweep gas flow rate in individual contactors or trains
	Uneven sweep gas flow rate in individual contactors	Measure sweep gas flow rate in individual contactors or trains Measure vacuum level in trains
	Air leaks in sweep or vacuum lines	Tighten gas side flange connections.
		Pressurize gas line and monitor to test for leaks.
		Soap test – look for bubbles.
		Pressure test – Pressurize then isolate and monitor for pressure decay.
		Electronic leak detection systems.
		Operate system and collect data points.
		Stop gas flow and operate in Vacuum only mode. Record conditions and outputs.
		Stop vacuum pump, open vacuum bypass manifold and start gas flow. Record conditions and outputs in vacuum mode.
		Contact 3M representative.
	High vacuum level.	Ensure that the vacuum system (pump & manifold) is sized correctly and that the vacuum manifold is sized to handle gas load for the system.
		Check system for air leaks. If the outlet dissolved gas concentration is within the sizing estimate limits, the leak is probably in the vacuum manifold after the contactor.
		Draw a vacuum on the contactor when it is filled with water and verify that it holds vacuum.
		Look for water accumulation in the vacuum piping.
		Does the vacuum line slope down from contactor to vacuum pump? If no, re-pipe per instructions or install a liquid /vacuum trap
		Disconnect the vacuum line from the contactor. If water drip rate from the lumen port, (without sweep gas) exceeds the normal expected range, contact a 3M representative.
	Condensation in contactor or vacuum lines	If contactor has been sitting wet while not in operation, there may be water condensation in the lumen.
		Remove condensate inside of the fibers with a gas purge following procedure outlined in section D.
		Look for water accumulation in vacuum pipe.
		Does vacuum line slope down from contactor to vacuum pump? If no, re-pipe or install liquid vacuum trap.
		Disconnect vacuum line from contactor. If water drip rate from the lumen port, (without sweep gas) exceeds the normal expected range, contact a 3M representative
	Liquid temperature below design specification	Raise temperature or add more contactors
	Liquid flow rate higher than design specification	Reduce flow rate or add more contactors
	Low sweep gas flow rate	Increase sweep gas flow rate.
	Unequal liquid flow through contactor trains	Verify train flow rate.
		Adjust valves accordingly to equalize flow rates.

High liquid-side pressure drop	Dust covers used in shipping may not have been removed	Verify dust covers/end cap plugs have been removed.
	Particulate accumulation on shell side	Check filter system.
		Clean contactors or backflush. Refer to 3M Liqui-Cel Membrane Contactor Cleaning and Storage Guidelines
		Replace contactors.
Significant liquid passage into gas stream	Verify the liquid inlet is connected to the shell side port	Change piping connections.
	Center seal O-rings may not be sealing (if applicable)	See Contactor Assembly and Disassembly Instructions for details on how to fix this problem or contact a 3M representative.
	Contactor shell side O-rings may not be sealing	Remove and install new O-rings if appropriate. See 3M™ Liqui-Cel™ Membrane Contactor Assembly and Disassembly for details
	Verify contactor integrity	Pressurize shell side with water to 4.1 barg (60 psi)
		Monitor for water flow rate from open gas side port(s).
	Membrane break through (wet-out). If surfactants, oils, and/or alcohols have been introduced to the membrane, wet-out may have occurred	Remove fluid and dry the membrane thoroughly. See Cleaning and Storage Guidelines for drying procedures
		Rinse, clean and dry the contactor. Refer to Cleaning and Storage Guidelines.
Nuts are seizing when tightened	The nuts should not be quick driven onto the bolts	Nuts should be driven slowly by hand to prevent galling. Apply proper lubrication to the bolts prior to installation.
	Using power driven tools can produce excessive friction and increase the risk of galling	

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