



3M™ Liqui-Cel™ Extra-Flow Membrane Contactors

Design and Operating Guidelines

For the following products:

2.5 × 8, 4 × 13, 4 × 28, 6 × 28, 8 × 20, 8 × 40, 8 × 80, 10 × 28, 14 × 28 and 14 × 40

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The 2.5 x 8, 4 x 13, 4 x 28, 6 x 28, 8 x 20, 8 x 40, 8 x 80 and 10 x 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. Our 10 x 28 high purity, 14 x 28 and 14 x 40 industrial products have a product classification – Category 1 per PED 97/23/EC and do carry a CE mark.

SAFETY INFORMATION:

Read, understand, and follow all safety information contained in these instructions prior to installation and use of the Liqui-Cel® Extra-Flow Membrane Contactors. Retain these instructions for future reference.

Intended Use:

This Liqui-Cel Membrane Contactor is intended to add to or remove dissolved gases from non-dangerous liquid streams. It is expected that all users be fully trained in the safe operation of membrane contactors. Membrane contactors are intended for installation and operation by qualified installers and operators in accordance with all operating guidelines, installation instructions, and any other industry requirements. Use in any other application may not have been evaluated by 3M and may lead to an unsafe condition.

EXPLANATION OF SIGNAL WORD CONSEQUENCES	
 WARNING:	Indicates a potentially hazardous situation, which, if not avoided, could result in death or serious injury and/or property damage.
 CAUTION:	Indicates a potentially hazardous situation which, if not avoided, may result in minor or moderate injury and/or property damage.
CAUTION:	Indicates a potentially hazardous situation, which, if not avoided, may result in property damage.

WARNING

To reduce the risks associated with explosion:

- DO NOT exceed maximum operating pressure or temperature limits.
- DO NOT exceed maximum liquid temperature or pressure limits.
- Ensure both gas/vacuum ports are not closed during operation.
- Over-pressurization of liquid and gas should be prevented by the installation of proper pressure relief valves.

To reduce the risks associated with hazardous voltage:

- Ensure electrical connections are properly grounded.
- Always use a grounded power supply of the appropriate voltage matching the system's vacuum pump or blower voltage with a 15 amp fuse protection and a local disconnect switch.
- Always verify the appropriate electrical connection with your local electrical code and replace plug as necessary.

CAUTION

To reduce the risks associated with hot surfaces:

- DO NOT touch the blower during operation.
- Always direct blower discharge away from the operator.
- Do not touch the membrane contactor during a hot sanitization cycle and allow enough time for the surface of the membrane contactor to cool.

To reduce the risks associated with impact:

- Always make sure the contactor is properly secured.

To reduce the risks associated with environmental contamination:

- At the end of useable life, dispose of the membrane contactor or cartridges in accordance with local regulations and laws.

To reduce the risks associated with damaging the membrane contactor:

- For all 2.5x8-inch, 4-inch and 10-inch membrane contactors, lumen side pressure should never exceed shell side pressure during cleaning.
- Do not expose the membrane to air when liquid or gas temperatures exceed 35° C (95° F).

NOTICE

- Avoid contacting membrane to surfactants or solvents to prevent membrane wet-out.
- Do not expose membrane to oxidizing species such as ozone, chlorine, hydrogen peroxide, peracetic acid, etc. to prevent membrane oxidation.
- Membrane contactors should not be stored where they are exposed to direct sunlight. Contactors should always be stored in sealed bags or shrink wrap material and in the original box or other opaque box.
- Store dry membrane contactor(s) at temperatures < 49° C. Store dry membrane contactor(s) at temperatures < 49° C (120° F) with low to moderate humidity levels (<60% relative humidity).
- Filtered, de-chlorinated, and deionized water is recommended for mixing cleaning solutions. Water containing sparingly soluble compounds of Ca, Mg, Fe, Al, etc. and silica (SiO₂) precipitate on to the membrane surface when there is a pH shift in the water.

I. Technology Description

Liqui-Cel® Membrane Contactors make it possible to transfer gas to or from an aqueous stream without dispersion. A membrane contactor can contain thousands of microporous polypropylene hollow fibers knitted into an array that is wound around a center tube. The hollow fibers are arranged with uniform spacing, allowing greater 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.

Although Liqui-Cel Membrane Contactors utilize a microporous membrane, the separation principle differs substantially from other membrane separations such as filtration and gas separation. With Liqui-Cel Membrane Contactors there is no convective flow through the 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 the target 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. Liqui-Cel Membrane Contactors are mechanical devices that do not require chemicals to operate.

A. Contactor Design

Several membrane contactor design variants are available to meet the needs of a broad range of applications and range of flow rates. Each variant is designed to maximize the liquid-gas contact area.

Extra-Flow - uses a central baffle to force liquids radially over the fiber array. Liquid flows on the outside (shell side) of the hollow fibers.

High Pressure - similar to the Extra-Flow with center baffle design, but with a different housing concept for high pressure applications. 8 x 40 and 8 x 80-inch contactors use this design.

Radial - uses a center tube with no direct outlet to force liquids radially across the fiber array. The 1 x 3 and 2 x 6 SuperPhobic® Contactors utilize this design.

MiniModule™ - liquid flows inside of the hollow fiber (lumen side). Most of the operating parameters listed in this guide do not apply to MiniModule™ because they are small in size and may have different system requirements. Instead, refer to the MiniModule™ startup and shutdown procedures located in the technical resources section at www.liqui-cel.com.

MicroModule™ - smallest contactor design available and utilizes shell side liquid flow. Due to their size, the operating parameters listed in this guide do not apply. Instead refer to the MicroModule™ startup and shutdown procedures found in the technical resources section at www.liqui-cel.com.

B. Membrane Selection

Liqui-Cel Membrane Contactors utilize a variety of membrane fiber types. The sales and technical service team will assist in making the appropriate membrane selection.

Gas Absorption

When using membrane contactors in gas absorption applications a gas is introduced on the inside (lumen side) of the hollow fiber membrane and the liquid phase is introduced to the outside (shell side) of the hollow fiber. The partial pressure of the gas and the water temperature controls the amount of gas dissolved in the liquid phase.

Gas Stripping

When using membrane contactors in gas stripping applications a vacuum or stripping gas, or combination of the two, is applied to the lumen side of the hollow fiber. The liquid stream is introduced to the outside of the fiber. The partial pressure of the target species in the gas phase is decreased to remove dissolved gases from the liquid phase.

C. Extra-Flow Product and Membrane Illustrations with Port Identification

Illustration 1: Liqui-Cel® Extra-Flow Contactor

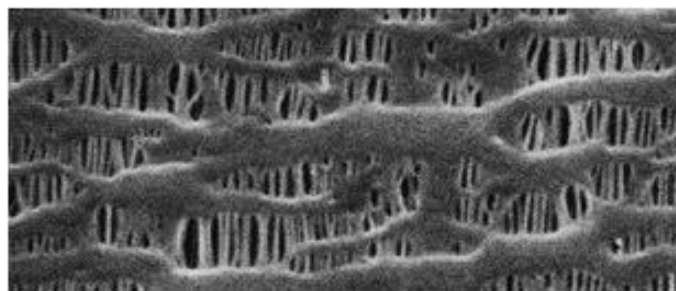
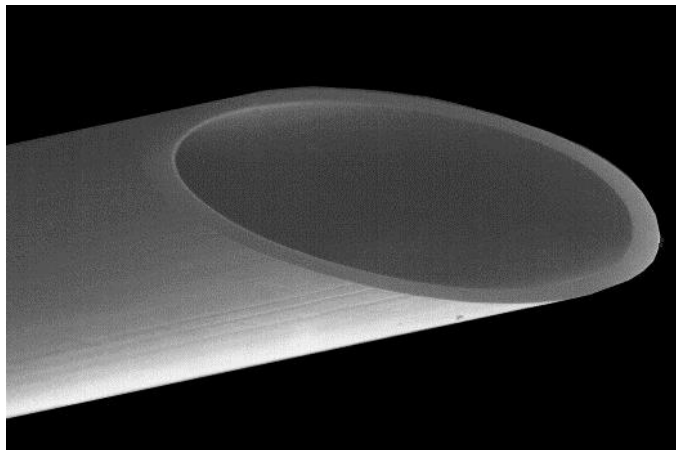
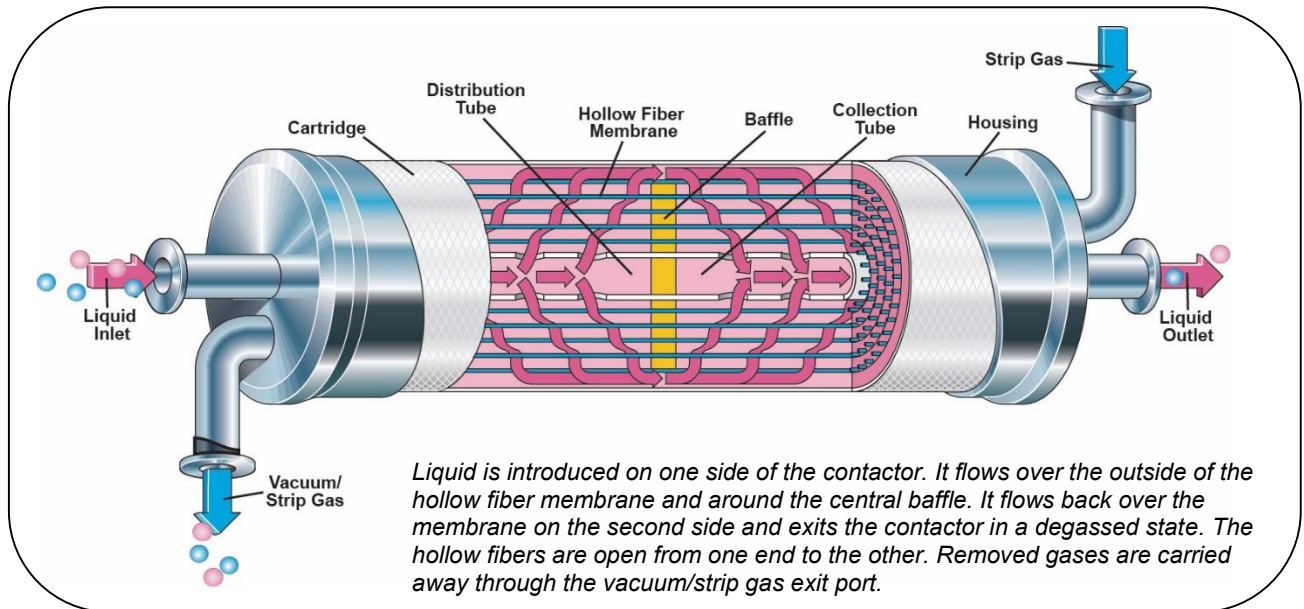


Illustration 2:
Scanning Electron Microscope (SEM) images of hollow fiber membrane. The porous surface can be seen in the bottom photo.

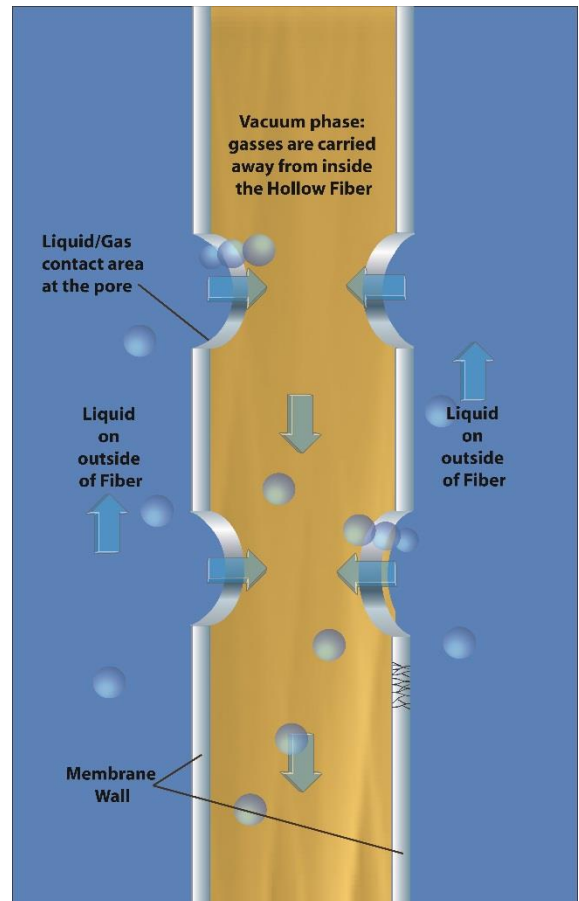


Illustration 3:
Cutaway of hollow fiber showing the gas and liquid flow paths.

II. Important Information on Protecting the Membrane and the Membrane Contactors

WARNING

To reduce the risks associated with explosion:

- DO NOT exceed maximum operating pressure or temperature limits.
- DO NOT exceed maximum liquid temperature or pressure limits.
- Ensure both gas/vacuum ports are not closed during operation.
- Over-pressurization of liquid and gas should be prevented by the installation of proper pressure relief valves.

CAUTION

To reduce the risks associated with impact:

- Always make sure the contactor is properly secured.

To reduce the risks associated with damaging the membrane contactor:

- For all 2.5x8-inch, 4-inch and 10-inch membrane contactors, lumen side pressure should never exceed shell side pressure during cleaning.
- Do not expose the membrane to air when liquid or gas temperatures exceed 35° C (95° F).
- All plastic port extensions should be supported to prevent bending of extensions under excessive piping loads.

NOTICE

- Avoid contact with surfactants/solvents or oxidants (e.g. ozone, chlorine) to the hydrophobic membrane to prevent wet-out or oxidation.
- Membrane contactors should not be stored where they are exposed to direct sunlight. Contactors should always be stored in sealed bags or shrink wrap material and in the original box or other opaque box.
- Store dry membrane contactor(s) at temperatures < 49° C (120° F). Store dry membrane contactor(s) at temperatures < 49° C (120° F) with low to moderate humidity levels (<60% relative humidity).
- Filtered, de-chlorinated, and deionized water is recommended for mixing cleaning solutions. Water containing metals such as Mg, Fe, Al, and SiO₂ may precipitate on to the membrane surface when there is a pH shift in the water.

PROTECTING THE MEMBRANE

A. General

- Liquid pressure should always exceed gas pressure inside the contactor.
- Never exceed pressure/temperature limits provided in this guide and on contactor datasheets.
- Do not allow transmembrane pressure differentials to exceed recommended limits. See page 32, section C for more information.

B. Oxidation

Exposing the hollow fiber membrane inside a 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 are listed below along with their relative oxidative strengths.

Oxidizing Species	Relative Oxidative Strength (eV)
F ₂	3.10 eV
OH [•]	2.80 eV
O [•]	2.42 eV
O ₃	2.07 eV
H ₂ O ₂	1.70 eV
Cl ₂	1.36 eV

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

Sources of oxidizing species may be present in the liquid or gas phases that come into contact with the hollow fiber membrane.

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

Common examples of oxidation risk

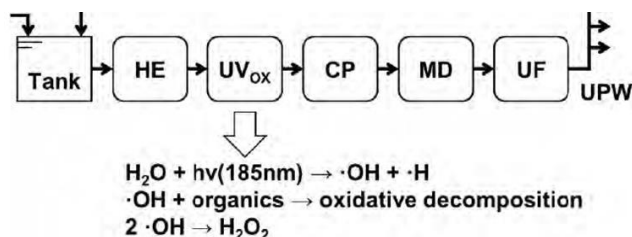
Oxygen in air - Air is commonly used as a sweep gas in membrane contactor operation. The oxygen (an oxidizing species) present in the air may cause some deterioration of the membrane hollow fiber, especially at elevated temperatures. When using air in the sweep gas mode, note the following information:

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

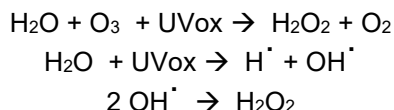
UV & Hydroxyl radicals - UV radiation is commonly used by itself or in conjunction with other oxidizing species to destroy DOC. When UV radiation is used by itself it may generate potent hydroxyl radicals along with additional hydrogen peroxide in water.

The hydroxyl radical is a species with a short half-life compared to dissolved ozone, but it has greater potential to cause oxidative damage. Therefore, it is recommended that the membrane contactors are located upstream of UV and ozonation process steps. If this is not possible, the contactors should never be located immediately following ozonation and UV radiation steps. Even placement further downstream of UV and ozonation may incur some risk of oxidation.



HE: Heat Exchanger, UVox: UV Oxidizer, CP: Cartridge Polisher, MD: Membrane Degasifier, UF: Ultrafiltration

In many systems, UV is used after ozonation step to break down ozone, which again creates more hydroxyl radical and H₂O₂ as shown in equations below.



When using an inert gas, such as nitrogen, in sweep gas mode or when operating in vacuum mode, note the following information.

Chlorine - Water and or liquids flowing through the contactor may contain high levels of chlorine. 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 $\leq 35^\circ\text{C}$ (95°F) could be used, depending on the operating mode. Be aware that some oxidation may still occur. The chart below provides some guidelines on chlorine limits. To help reduce the effects of membrane oxidation always maintain a constant sweep of inert gas, especially during any on-and-off operation of the feedwater stream. In vacuum mode, leave the vacuum source in operation. The sweep gas must remain as an inert gas. Air temperatures exceeding 35°C (95°F) may reduce membrane life.

Operating Mode	Maximum Recommended Chlorine Concentration	Suggested Chlorine Concentration Limit
Combo (N ₂ Sweep)	< 1ppm	< 0.5ppm
Air Combo	< 0.1ppm	< 0.05ppm
Air Sweep	0ppm	0ppm
Vacuum Only	< 1ppm	< 0.5ppm

C. Surfactants and Organic Solvents

Avoid contact with surfactants and organic solvents with low surface tension (such as alcohols) when using polypropylene X-40, X-50 and XIND 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.

Operating outside of these guidelines may negatively impact contactor life and/or void any warranty that may exist. If you have questions about oxidation, fouling or system design, contact a 3M representative that represents the Liqui-Cel® brand.

PROTECTING OTHER EQUIPMENT IN YOUR SYSTEM

If membrane failure occurs for any reason, water may flow to the gas side of the membrane. This would happen because the liquid must always maintain a greater pressure than the gas phase. In normal operating mode, gases exit the membrane system at atmospheric pressure or under vacuum and in case of membrane failure, water will flow out of the vacuum/gas phase ports. In the extreme case of a major water bypass to the drain, water will stop flowing in its regular path. To prevent any equipment damage downstream of the membrane system, a low pressure alarm switch or a flow switch is recommended.

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.

Operating outside of these guidelines can negatively impact the membrane life and/or void the performance warranty. If you have questions about your system design, contact your 3M representative.

During startup the high vacuum pressure switch should have a time delay allowing the vacuum level to come down.

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 contactors. The piping must be designed to drain this water from the contactors and out of the piping. If the water vapor is not removed, it can collect over time in the lumens and reduce the contactor's performance. The condensation rate will depend on the liquid temperature. The warmer the liquid stream, the higher the water-vapor transport rate. This condensation phenomenon is normal.

WARNINGS OF MISUSE

Avoid the following: water hammer, over-pressurization, dropping of contactors and over-torquing the end cap clamp bolts, if applicable. Using power driven tools to tighten nuts can produce excessive friction and increase the risk of thread damage. It is also important to follow recommendations when supporting 14-inch contactors in a system. The bolt flange that attaches the end caps to the vessel should not be used to support the weight of the contactor.

Also note that if membrane failure occurs, liquid could enter the gas side. Although this is extremely rare, a pressure-limiting device downstream of the gas outlets would protect downstream devices. Also note that the membrane will allow gases to pass from the gas side to the liquid side and vice versa if water is not present on one side of the membrane. Therefore, any system pressure tests with compressed gas should be used only to the maximum listed pressures as listed in Tables 6-12 of this guide.

III. Gas Stripping Modes

WARNING

To reduce the risks associated with explosion:

- DO NOT exceed maximum operating pressure or temperature limits.
- DO NOT exceed maximum liquid temperature or pressure limits.
- Ensure both gas/vacuum ports are not closed during operation.
- Over-pressurization of liquid and gas should be prevented by the installation of proper pressure relief valves.

To reduce the risks associated with hazardous voltage:

- Ensure electrical connections are properly grounded.
- Always use a grounded power supply of appropriate voltage matching the system voltage with fuse protection and a local disconnect switch.
- Always verify the appropriate electrical connection with your local electrical code and replace plug as necessary.

CAUTION

To reduce the risks associated with hot surfaces:

- DO NOT touch the blower during operation.
- Always direct blower discharge away from the operator.

To reduce the risks associated with impact:

- Always make sure the contactor is properly secured.

To reduce the risks associated with damaging the membrane contactor:

- For all 2.5x8-inch, 4-inch and 10-inch membrane contactors, lumen side pressure should never exceed shell side pressure during cleaning.
- Do not expose the membrane to air when liquid or gas temperatures exceed 35° C (95° F).

NOTICE

- Avoid contact with surfactants/solvents or oxidants (e.g. ozone, chlorine) to the hydrophobic membrane to prevent wet-out or oxidation.
- Membrane contactors should not be stored where they are exposed to direct sunlight. Contactors should always be stored in sealed bags or shrink wrap material and in the original box or other opaque box.
- Store dry membrane contactor(s) at temperatures < 49° C (120° F). Store dry membrane contactor(s) at temperatures < 49° C (120° F) with low to moderate humidity levels (<60% relative humidity).
- Filtered, de-chlorinated, and deionized water is recommended for mixing cleaning solutions. Water containing metals such as Mg, Fe, Al, and SiO₂ may precipitate on to the membrane surface when there is a pH shift in the water.
- All plastic port extensions should be supported to prevent bending of extensions under excessive piping loads.

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

- Sweep Gas
- Vacuum
- Sweep-Assisted Vacuum (Combo Mode)
- Blower in Suction Mode (Induced Draft Blower) for economical CO₂ removal

A. Sweep Gas Mode

Operation Note:

Using on-site compressed dry air at temperatures below 30 °C as a sweep gas is a very economical operating mode for removing carbon dioxide from the liquid stream.

Sweep gas mode is a process by which a gas in the lumen side of the contactor flows counter-current to the water flow. By choosing a sweep gas that is different from the gas targeted for removal, a partial pressure gradient is created between the liquid phase (shell side) and the gas phase (lumen side). This forces the target gas to transfer to the lumen side and be swept away. The purity of the sweep gas will impact the dissolved gas level that can be achieved at the liquid outlet. Therefore, a minimum of ISO Class 1 air with an oil content of 0.01 mg/m³ or less is recommended. When using the air stripping technique, the liquid stream will become saturated with air. The same principle applies to MiniModule™. The gas phase, however, is on the shell side of the contactor while the liquid phase is on the lumen side.

Gas Side Configuration and Operation

Minimum instrumentation recommended to design a sweep gas line to Liqui-Cel® Membrane Contactors when using compressed gases (see **Figures 1 & 2**).

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

Compressed gases or oil-free compressed dry air (for carbon dioxide removal) can be used as a sweep gas. To operate the system, follow these steps:

1. Set the pressure by adjusting the PCV-201 valve. It is recommended that the gas supply pressure to contactors is regulated to < 0.7 kg/cm² (< 10 psig, 0.69 bar).
Note: Liquid pressure should always exceed gas pressure inside the contactor. Do not exceed transmembrane pressure differentials. See page 32, section C for more information. If operating above the recommended gas pressure, liquid pressure must be maintained at all times. In the event that liquid pressure drops or stops during operation when gas pressure is greater than 0.7 kg/cm² (10 psig, 0.69 bar) the transmembrane pressure differential will exceed the recommended limit and may damage the contactor.

2. Set the recommended total sweep flow rate by adjusting the V-202 valve and the reading on the FI-201 flowmeter.
3. Introduce fresh sweep gas into each contactor.
4. Vent the outlet gases to an open area to avoid possible oxygen depletion within the operating area.
5. If using compressed dry air, make sure that it is oil-free. A 0.2-micron filter located prior to the PCV-201 valve is highly recommended for high purity applications. A 1.0-micron filter rating is typically sufficient for industrial applications.

If compressed gases or oil-free compressed dry air are not available, for CO₂ removal a blower may be used in suction mode to create an air sweep flow in contactor. A sizing program (available from 3M) can calculate the pressure drop on the gas side expressed in inches of water. Use this information to choose the blower size. When using a blower, follow steps 2 to 3 listed above.

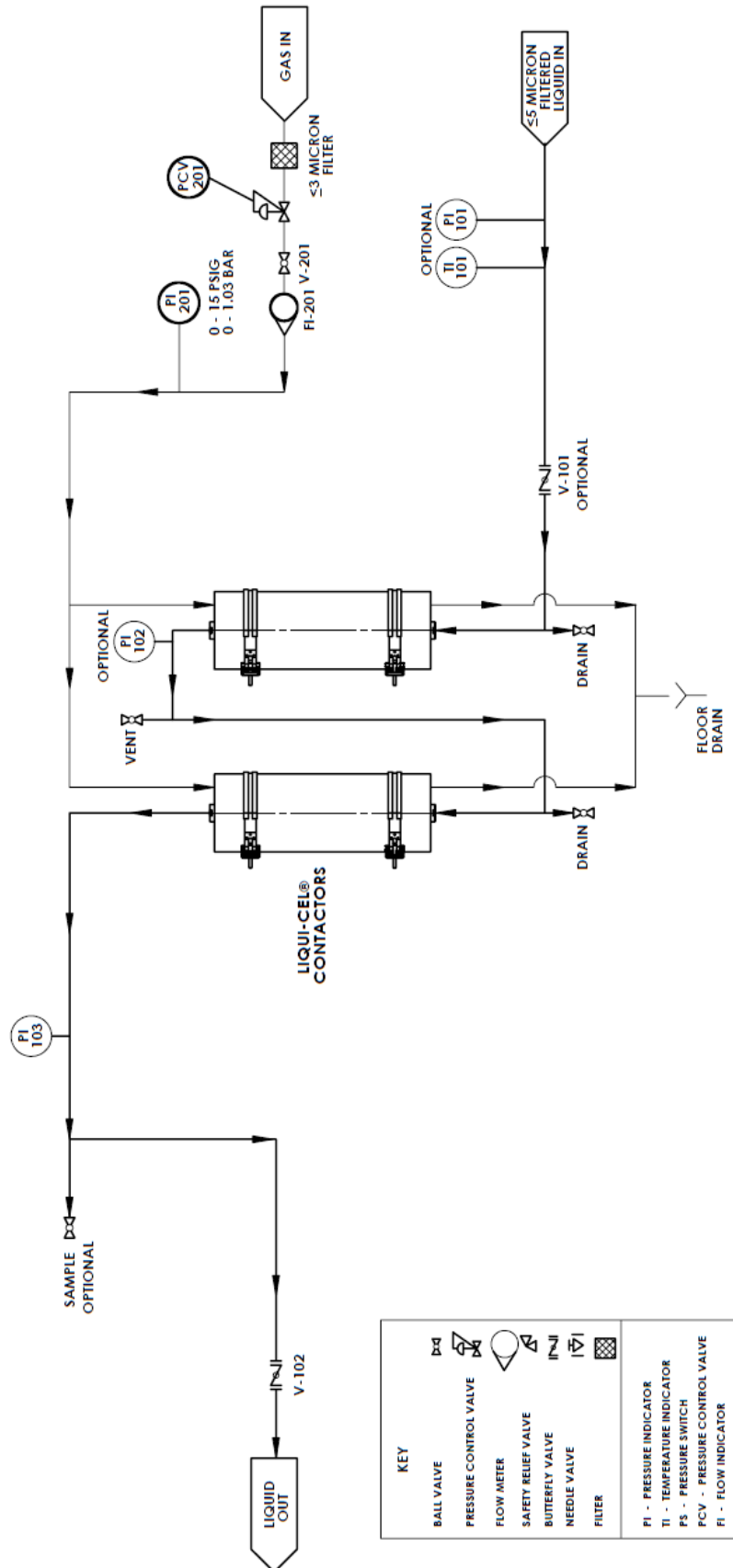
Note: It is also important that the blower does not increase the air temperature to >35 °C (95 °F). Air warmer than this can have a negative impact on fiber life. We recommend using the blower in suction mode at the bottom of the contactor for this reason. See section C on combo mode for more information.

Table 1: Typical Air-Sweep Requirements for CO₂ Removal*

Contactor	Air Sweep-Only Mode	
	scfm	Nm ³ /hr
2.5 x 8	0.25 – 1.25	0.4 – 2.0
4 x 13	1 – 5	1.6 – 7.9
4 x 28	1 – 10	1.6 – 15.8
6 x 28	2 – 10	3.2 – 15.8
8 x 20 PVC	3 – 15	4.7 – 23.7
8 x 20 SS	Not Applicable	Not Applicable
8 x 40	5 – 20	7.9 – 31.7
8 x 80	Not Recommended	Not Recommended
10 x 28	5 – 30	7.9 – 47.5
14 x 28	10 – 50	15.8 – 79.1
14 x 40	Not Recommended	Not Recommended

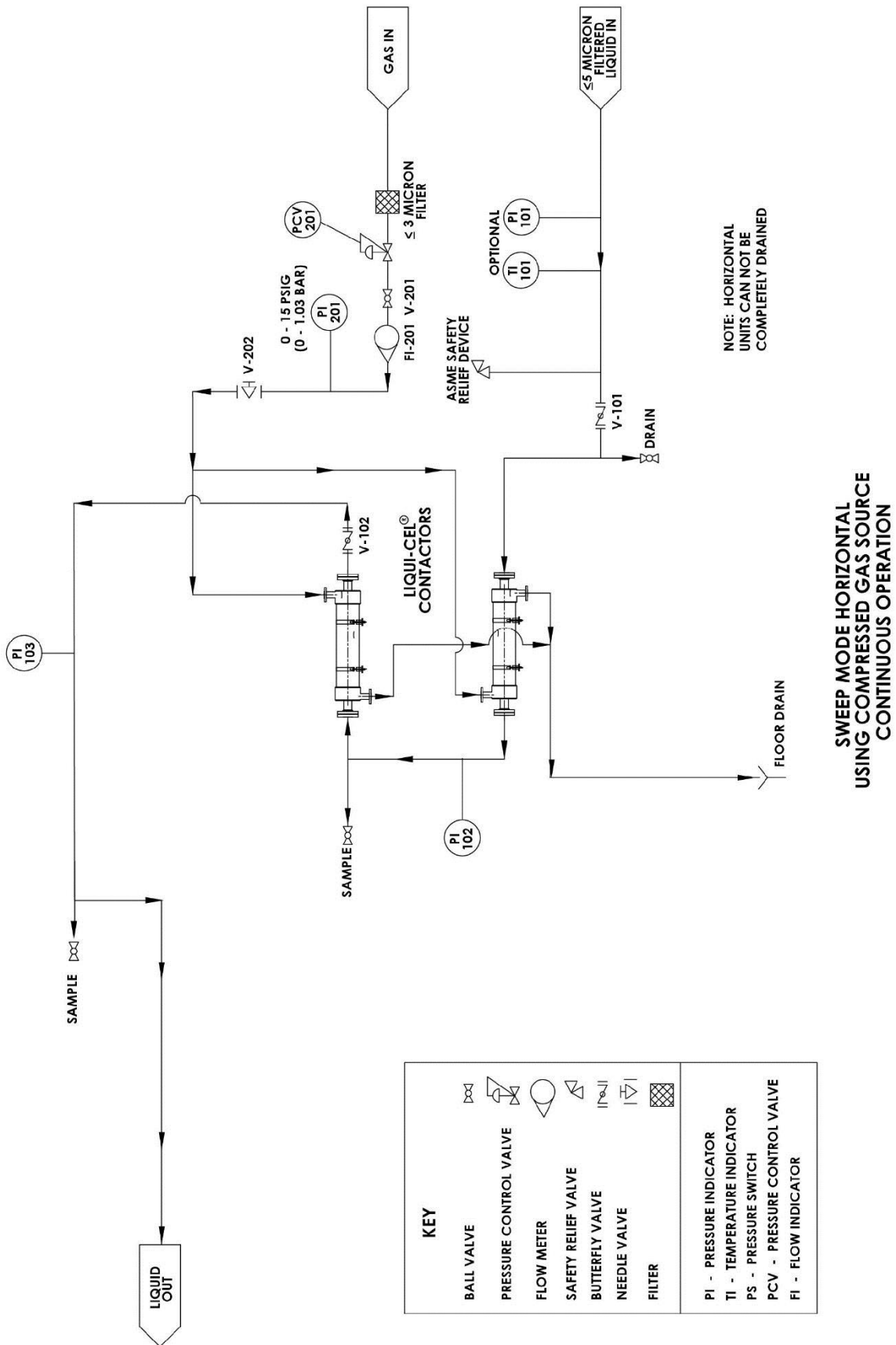
* Values shown represent typical sweep flow rates used in most operating systems. However, the contactors can be operated at higher sweep rates. For water side configuration and operation, check *General System Design Guidelines* in Section III.

Figure 1. Generic P & ID for Vertical Mounting sweep-gas operation with two contactors in series



**SWEEP MODE VERTICAL
USING COMPRESSED GAS SOURCE**

Figure 2. Generic P & ID for Horizontal Mounting sweep-gas operation with two contactors in series



B. Vacuum Mode

Operation Note:

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

Vacuum mode is a process in which a vacuum is applied to the lumen side of the contactor. A vacuum should be drawn from both lumen ports, as opposed to a single lumen port, to improve bulk gas stripping efficiency. When the 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 the shell side to the lumen side. These gases are discharged through the vacuum pump. Vacuum levels affect removal efficiency. The deeper the vacuum, the lower the dissolved gas outlet concentrations will be. **Table 2** illustrates gas removal at different vacuum levels. The same principle applies to MiniModule™, however, the gas/vacuum phase is on the shell side of the contactor while the liquid phase is on the lumen side.

Table 2: Outlet Dissolved Oxygen Concentration, Using the Vacuum Mode

The following table provides an illustration of how vacuum levels affect performance. All other operating parameters were the same except the vacuum level.

Vacuum Level (absolute gas pressure, assuming 760 mm Hg atmospheric pressure)	26 in. Hg (100 mm Hg)	27 in. Hg (74 mm Hg)	28 in. Hg (50 mm Hg)	28.5 in. Hg (36 mm Hg)
Outlet Concentration (typical), ppb	1345	1015	560	345

Conditions: Two 4x28, X-40 contactors in series
 Flow rate 20 gpm (4.5 m³/hr)
 Temperature 77 °F (25 °C)

Calculations assume that dissolved oxygen and nitrogen levels in water at the contactor inlet are based on normal air-saturation conditions.

Vacuum-Side Configuration and Operation

Minimum instrumentation that is recommended to operate in the vacuum mode. (See **Figures 3, 4, 5, 6 & 7**).

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

To operate the system, follow these steps:

Follow the vacuum pump manufacturer's instructions for startup.

1. Open the V-301 valve
2. Turn on the vacuum pump
3. Slowly open the water inlet valve, V-101

The successful operation of a Liqui-Cel® or SuperPhobic® 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 these recommendations when designing a vacuum system:

1. 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 contactors to allow this water to drain from the 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 contactors. The condensation rate will depend on the liquid temperature. The warmer the liquid stream, the higher the water vapor transport rate. This condensation phenomenon is normal.

2. 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 (m³/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 make-up water line. 3M offers vacuum pumps in addition to membrane contactors. (See **Figures 3 and 4.**)

For water side configuration and operation, check the General System Design Guidelines in Section III.

Warning & 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 3. Generic P & ID for Vertical Mounting vacuum mode operation with two contactors in series

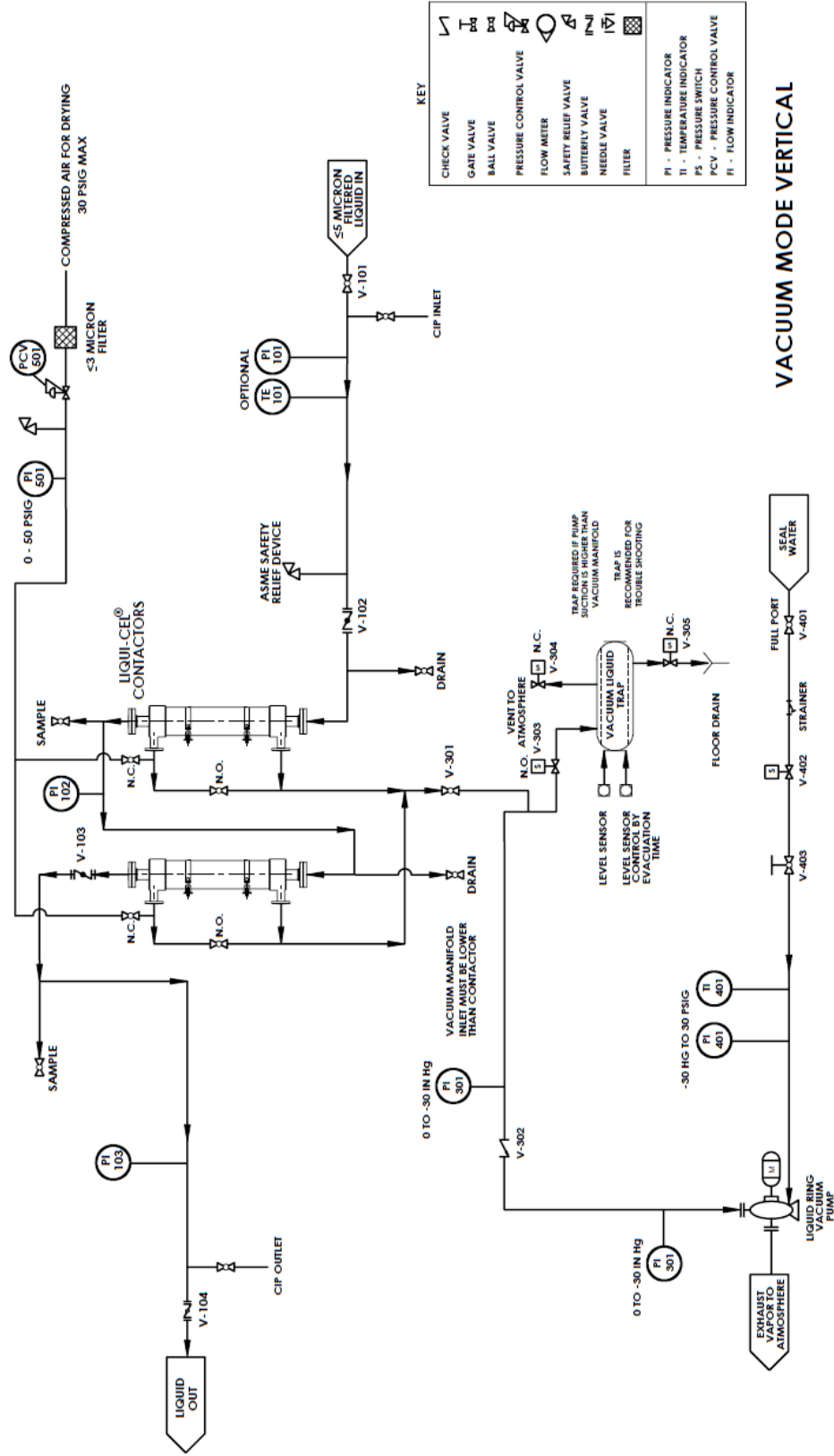
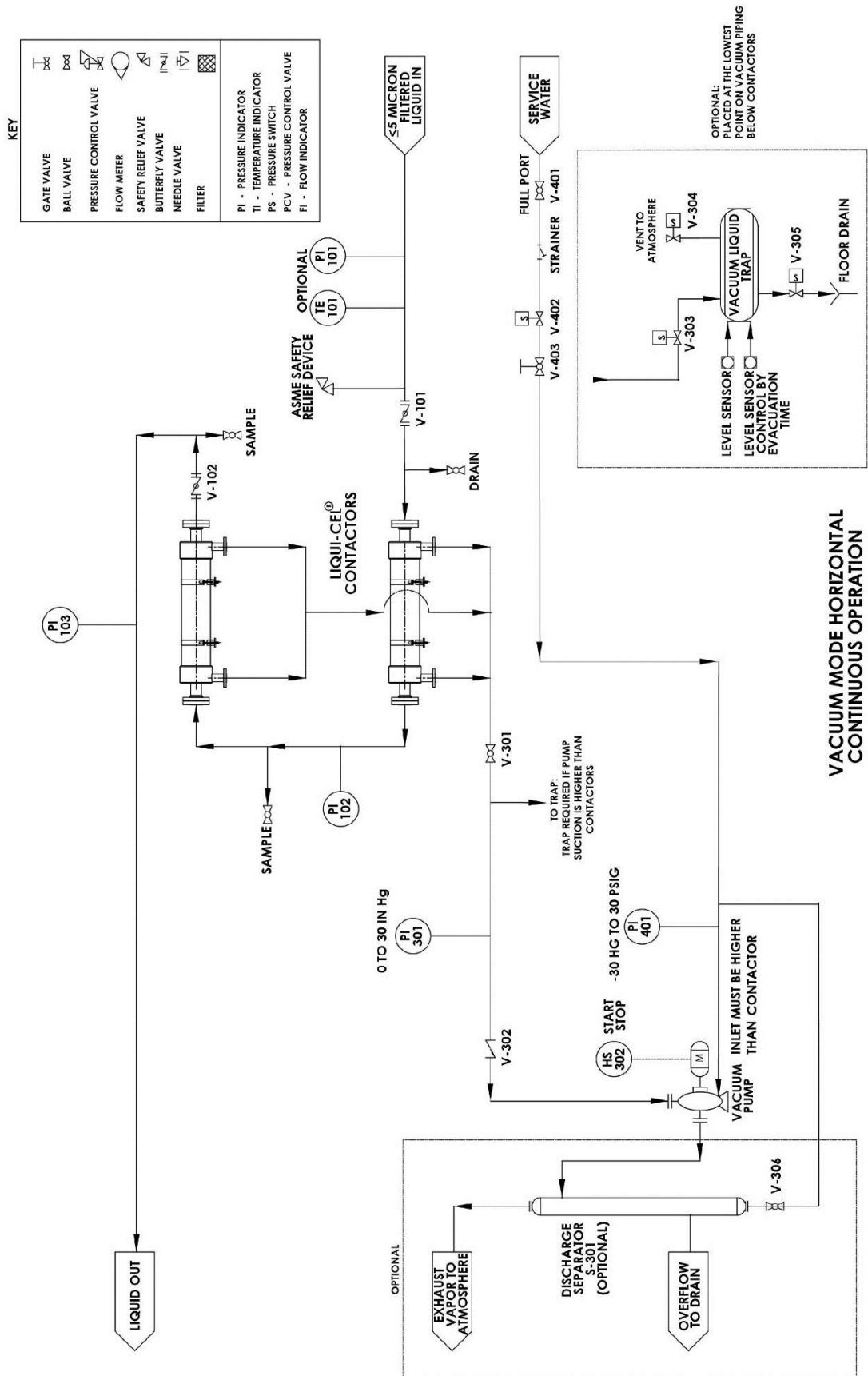


Figure 4. Generic P & ID for Horizontal Mounting vacuum mode operation with two contactors in series



C. Sweep-Assisted Vacuum (COMBO)

Operation Note:

Sweep-assisted vacuum is the most efficient way to achieve low levels of dissolved oxygen or low levels of carbon dioxide in water.

Sweep-Assisted Vacuum (Combo Mode) is a method in which a sweep gas is introduced to one lumen side port of the contactor, while the other lumen side 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 26 to 28 in. Hg gauge (50 to 100 mm Hg absolute at sea level).

Sweep and Vacuum-Side Configuration and Operation

Gas Side:

Minimum instrumentation that is recommended to connect a sweep line to the Liqui-Cel® Membrane Contactor operating in a Combo mode (see **Figures 5, 6 & 7**):

- Pressure regulator valve (PCV-201), required only when using compressed gas as sweep
- Needle valve (V-202)
- Compound Gauge (PI 201), required only when using compressed gas as sweep
- Flowmeter (FI-201)

Compressed gas or oil-free compressed dry air (for carbon dioxide removal) can be used as the sweep gas. To operate the system in combo mode, follow these steps:

1. Startup as described in vacuum mode operation.
2. Regulate gas supply pressure at $< 0.07 \text{ kg/cm}^2$ ($< 1 \text{ psig}$, 0.069 bar), by adjusting PCV-201.
3. Set the recommended total sweep flow rate by adjusting the V-202 valve and the reading on the FI-201 flowmeter.
4. Introduce fresh sweep gas into each contactor.
5. 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 1.0-micron filter rating is sufficient for industrial applications.

The needle valve (V-202) is installed on the sweep gas inlet line between the 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.

Note: For CO₂ removal, room air can be used, if a blower in suction mode is utilized to pull the room air into contactors. See section D below for more operating details. If room air is used, PCV-201 is not needed.

Vacuum Side:

The following is a list of the minimum instrumentation that is recommended to operate in Combo mode. (See **Figures 5, 6 & 7**):

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

The successful operation of a Liqui-Cel or SuperPhobic® Membrane Contactor degasification 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:

1. 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.
- 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 contactors to allow this water to drain from the 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 affect the performance of the 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 lumens with sweep gas or air at high flow rate for 5-30 minutes will facilitate clearing water vapor out of the lumens.

Additionally, when operating in sweep or combo mode with low flow rates in smaller contactors (<6-inch), we recommend vertically mounting the contactors with water flowing from bottom to top and sweep flowing from top to bottom. The downward sweep used in vertically mounted contactors facilitates keeping the lumens purged of condensation.

2. 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 (m³/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 make up water line. 3M offers vacuum pumps in addition to membrane. (See **Figures 5, 6 & 7.**)

Table 3: Typical Sweep Range for Combo Mode*

Contactor	Typical Air Sweep Combo Mode		Typical Nitrogen Sweep Combo Mode	
	Nm ³ /hr	Scfm	Nm ³ /hr	scfm
2.5 x 8	0.1 – 0.4	0.05 – 0.25	0.03 – 0.16	0.02 – 0.1
4 x 13	0.3 – 1.6	0.2 – 1	0.2 – 0.8	0.1 – 0.5
4 x 28	0.3 – 3.2	0.2 – 2	0.2 – 1.6	0.1 – 1
6 x 28	0.6 – 3.2	0.4 – 2	0.2 – 1.6	0.1 – 1
8 x 20 PVC	0.8 – 7.9	0.5 – 5	Not Applicable	
8 x 20 SS	Not Applicable		0.3 – 1.6	0.2 – 1
8 x 40	1.6 – 6.3	1 – 4	0.6 – 1.3	0.4 – 0.8
8 x 80	Not Recommended		0.8 – 1.6	0.5 – 1
10 x 28	3.2 – 15.8	2 – 10	0.6 – 1.6	0.4 – 1
14 x 28	4.7 – 23.7	3 – 15	0.8 – 1.6	0.5 – 1
14 x 40	Not Recommended		0.8 – 1.6	0.5 – 1

* Values shown represent typical sweep flow rates used in most operating systems. However, the contactors can be operated at higher sweep rates.

For water side configuration and operation, check General System Design Guidelines in Section III.

Warning & 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 5. Generic P & ID for Vertical Mounting sweep-assisted (Combo) operation with two contactors in series

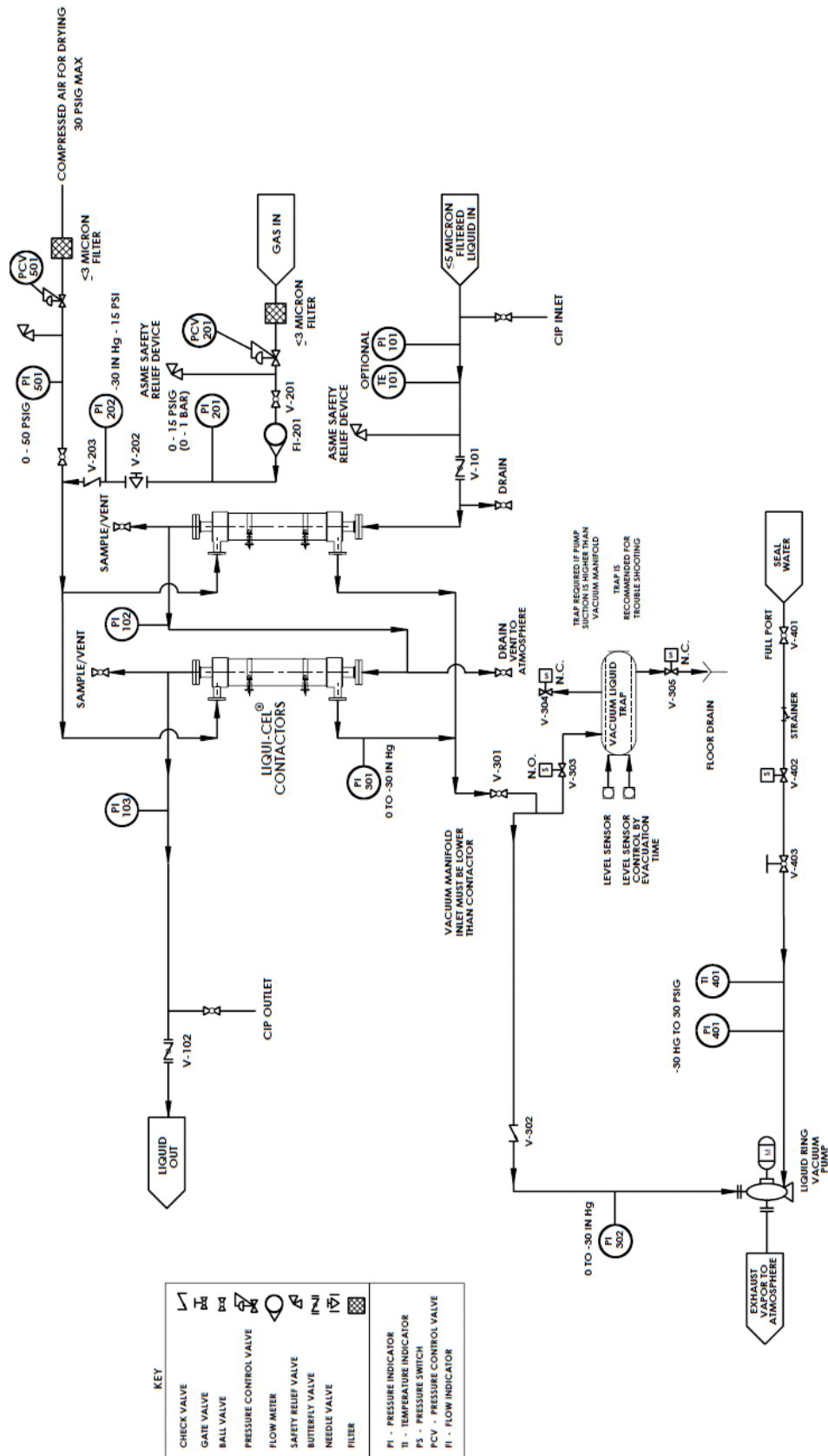


Figure 6. Generic P & ID for Horizontal Mounting sweep-assisted (Combo) operation with two contactors in series

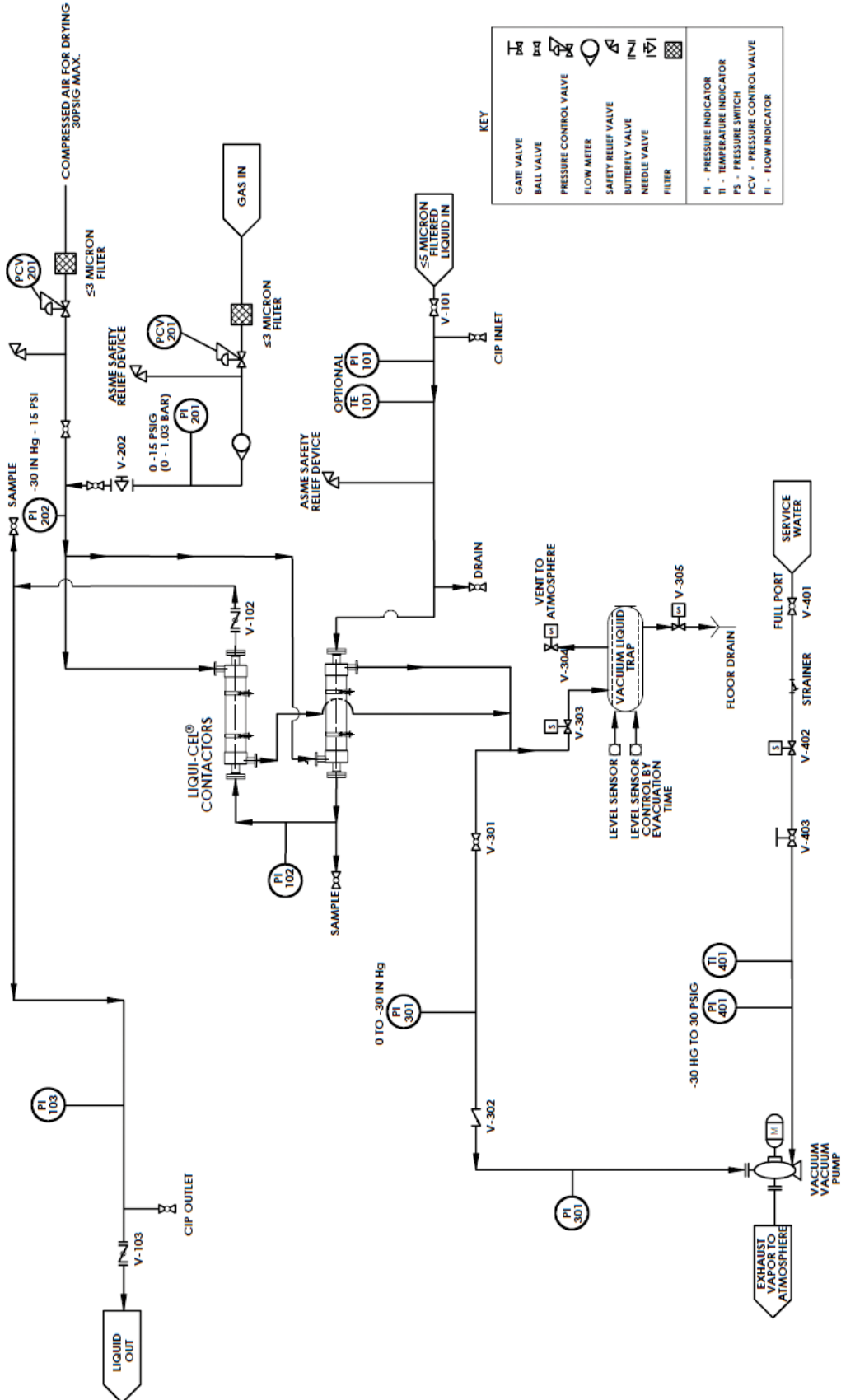
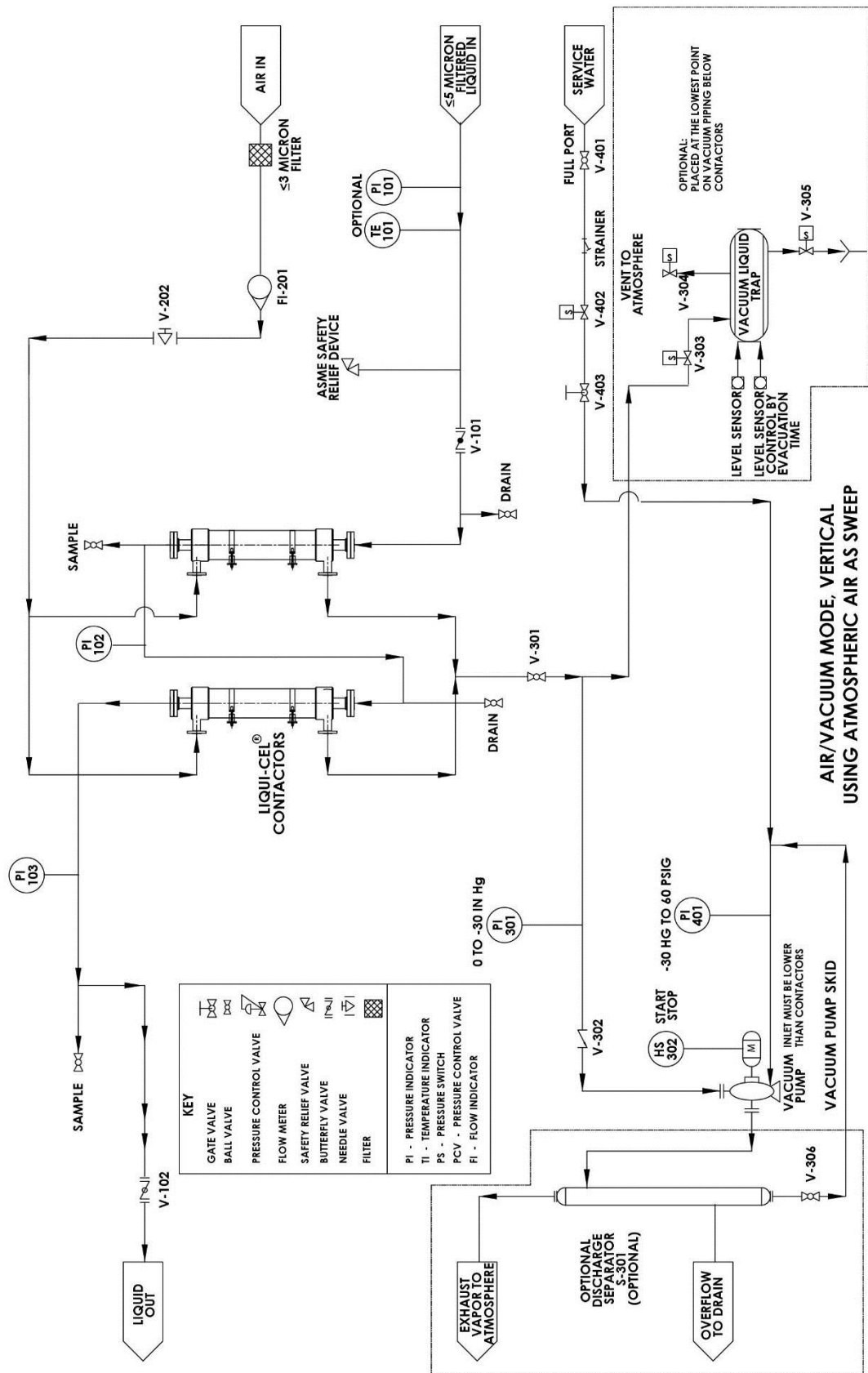


Figure 7. Generic P & ID for Air/Vacuum Mode, vertical using atmospheric air as sweep (two contactors in series)



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

Using a blower in suction mode and pulling in atmospheric air is a low cost alternative to using compressed air for carbon dioxide removal. However, it is critical that blower exhaust is piped away from the air intake ports of the contactors. Dissolved CO₂ levels down to 5 ppm in water can be achieved using this method. Lower levels of CO₂ removal to <1 ppm can be obtained with vacuum and air sweep combo mode.

Gas Side:

Minimum instrumentation recommended to pull atmospheric air into to the Liqui-Cel® Membrane Contactor by using a blower in suction mode (see **Figures 8 & 9**):

- Needle valve (V-202)
- Flowmeter (FI-201)
- Liquid trap
- Air filter <1 microns

For carbon dioxide removal using a blower in suction mode, follow these steps:

1. Turn on blower
2. Set air flow
3. Introduce water to Liqui-Cel Contactors

Liquid Side:

Minimum instrumentation recommended to operate a blower in suction mode while pulling in atmospheric air. (See **Figures 8 & 9**):

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

The successful operation of a 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:

1. 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 contactors and the blower suction port to protect the blower from premature failure due to water vapor impacting the blower.

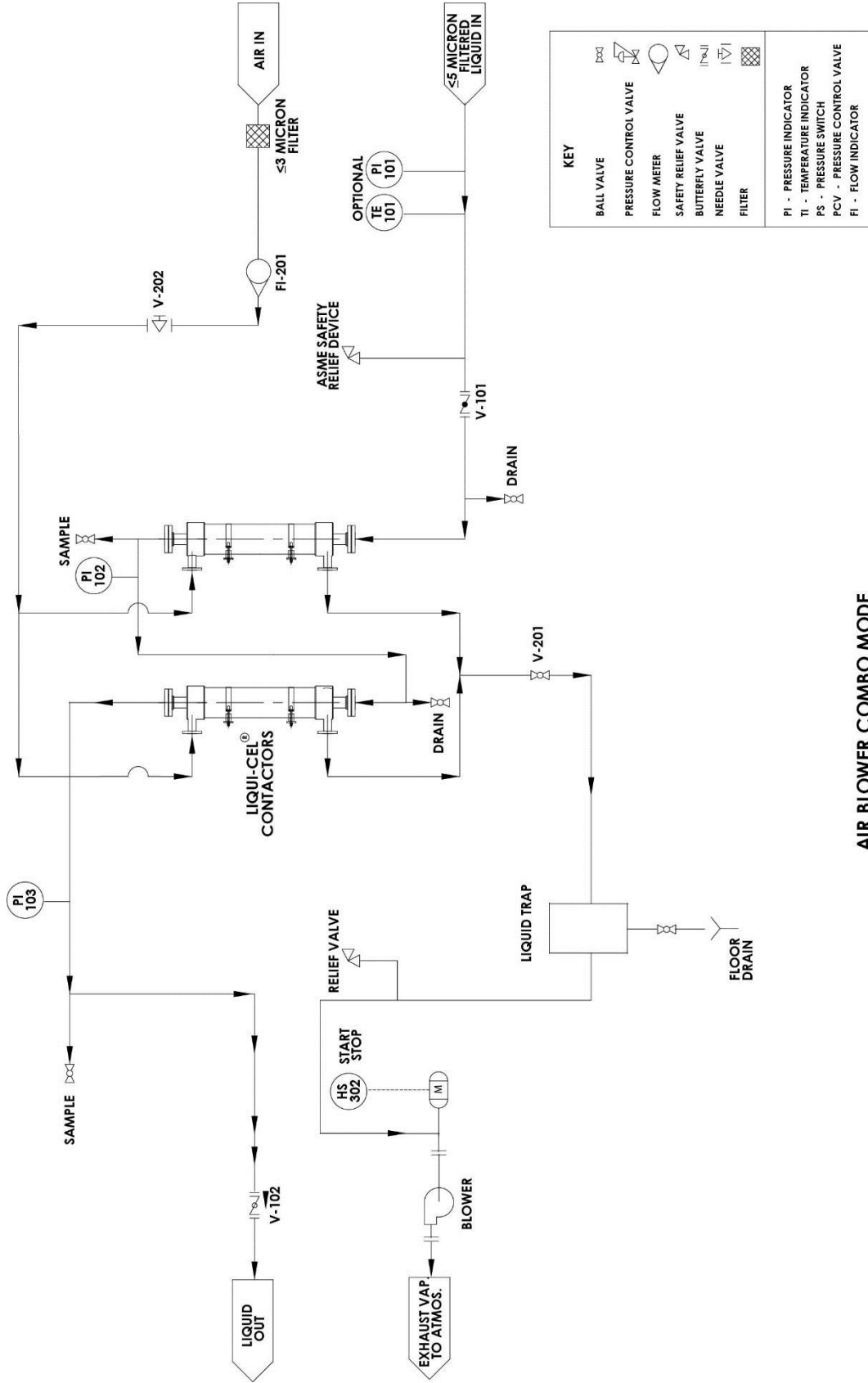
2. Blower Type and Sizing

- Utilize the sizing program or contact your local 3M representative to estimate the air sweep needed expressed in Cubic Feet per Minute (CFM) or Cubic Meters per Hour (m³/H) and the air pressure drop across the contactor expressed in mm Water Column (WC) or inch of WC. These two values will determine the size of the blower.
- A regenerative type blower is recommended. There are many brands of blowers; choose the one that is appropriate for the intended application or call a 3M representative for assistance.

Table 4: Sweep Range for Liqui-Cel® Contactors with a Blower Operated in Suction Mode

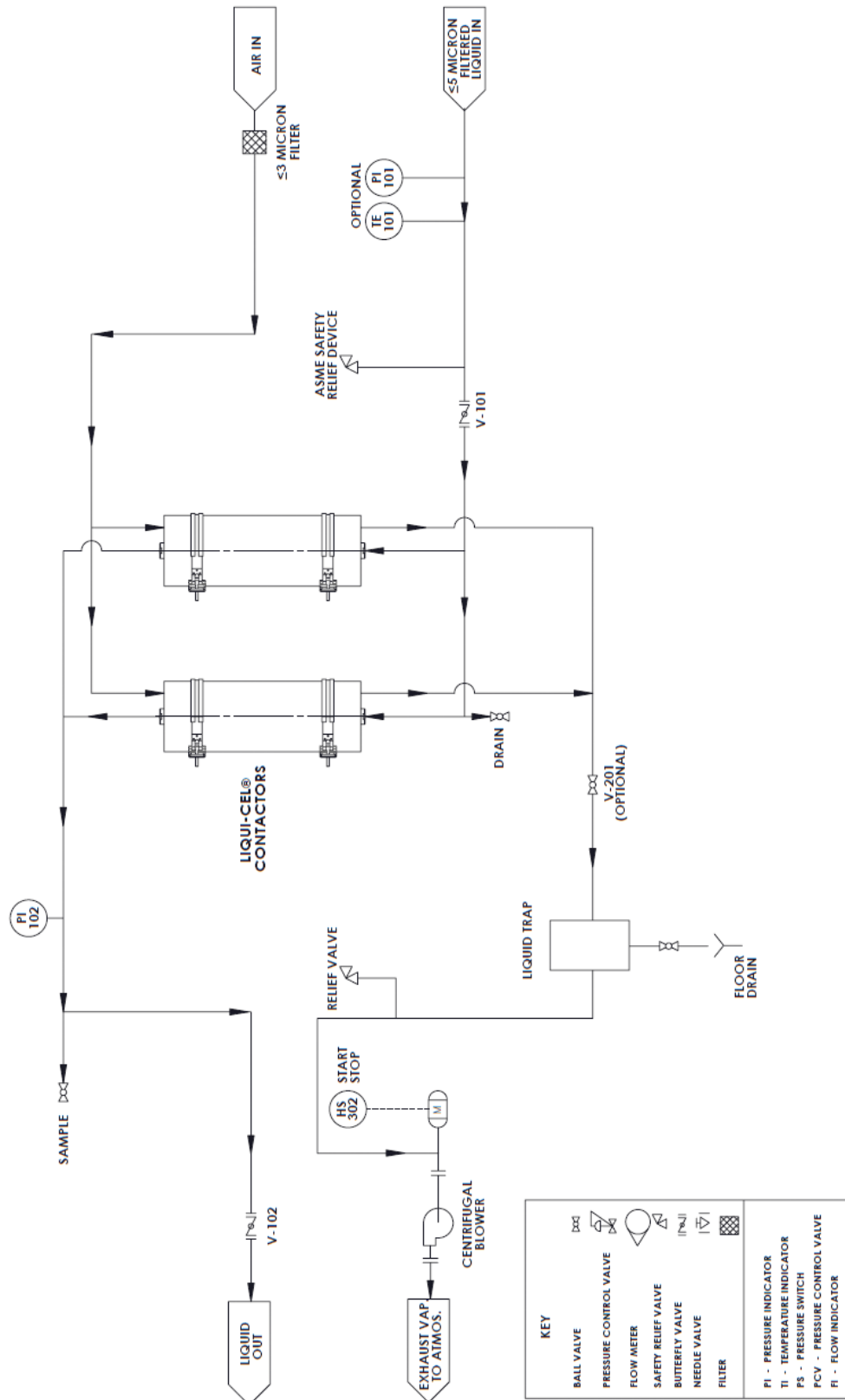
Typical Air Sweep per Contactor		
Contactor	m ³ /hr	(scfm)
4 x 13	1.6 – 7.9	1 – 5
4 x 28	1.6 – 15.8	1 – 10
6 x 28	3.2 – 15.8	2 – 10
8 x 20	4.7 – 23.7	3 - 15
10 x 28	7.9 – 47.5	5 - 30
14 x 28	15.8 – 79.1	10 - 50

Figure 8. Generic P & ID for vertical using blower to pull in atmospheric air two contactors in series



AIR BLOWER COMBO MODE
 USING BLOWER TO PULL IN ATMOSPHERIC AIR
 (SERIES CONFIGURATION)

Figure 9. Generic P & ID for, vertical using blower to pull in atmospheric air (two contactors in parallel configuration)



IV. General System Design Guidelines

The following guidelines apply to all gas removal techniques.

WARNING

To reduce the risks associated with explosion:

- DO NOT exceed maximum operating pressure or temperature limits.
- DO NOT exceed maximum liquid temperature or pressure limits.
- Ensure both gas/vacuum ports are not closed during operation.
- Over-pressurization of liquid and gas should be prevented by the installation of proper pressure relief valves.

To reduce the risks associated with hazardous voltage:

- Ensure electrical connections are properly grounded.
- Always use a grounded power supply of appropriate voltage matching the system voltage with fuse protection and a local disconnect switch.
- Always verify the appropriate electrical connection with your local electrical code and replace plug as necessary.

CAUTION

To reduce the risks associated with hot surfaces:

- DO NOT touch the blower during operation.
- Always direct blower discharge away from the operator.
- Do not touch the membrane contactor during a hot sanitization cycle and allow enough time for the surface of the membrane contactor to cool.

To reduce the risks associated with impact:

- Always make sure the contactor is properly secured.

To reduce the risks associated with damaging the membrane contactor:

- For all 2.5x8-inch, 4-inch and 10-inch membrane contactors, lumen side pressure should never exceed shell side pressure during cleaning.
- Do not expose the membrane to air when liquid or gas temperatures exceed 35° C (95° F).
- All plastic port extensions should be supported to prevent bending of extensions under excessive piping loads.

NOTICE

- Avoid contact with surfactants/solvents or oxidants (e.g. ozone, chlorine) to the hydrophobic membrane to prevent wet-out or oxidation.
- Filtered, de-chlorinated, and deionized water is recommended for mixing cleaning solutions. Water containing metals such as Mg, Fe, Al, and SiO₂ may precipitate on to the membrane surface when there is a pH shift in the water.

Important Notes:

- For **8x80-inch membrane contactors only** - It is recommended that both ends of the contactor are accessible to allow for cartridge change-out.
- For **8x20-inch PVC membrane contactors only** - It is recommended to avoid the use of metal fittings whenever possible. No more than 3 turns past hand-tight engagement is recommended when connecting to the Lumen ports.

A. Flow Pattern Configurations

1. Determination of Series and Parallel Configuration

Each type of Liqui-Cel® Membrane Contactor has a maximum flow rate. For system flow rates that exceed the individual contactor flow rate, it is necessary to split the flow into parallel trains. To determine the minimum number of parallel trains, divide the total system flow rate by the maximum flow rate provided in **Table 5**.

Table 5: Minimum and Maximum Contactor Flow Rates

Contactor	Minimum Flow Rate	Maximum Flow Rate
2.5 x 8 Extra-Flow or SuperPhobic®	0.1 m ³ /hr (0.5 gpm)	0.7 m ³ /hr (3 gpm)
4 x 13 Extra-Flow	0.5 m ³ /hr (2 gpm)	3.4 m ³ /hr (15 gpm)
4 x 13 SuperPhobic®	0.2 m ³ /hr (1 gpm)	3.4 m ³ /hr (15 gpm)
4 x 28 Extra-Flow	0.9 m ³ /hr (4 gpm)	6.8 m ³ /hr (30 gpm)
4 x 28 SuperPhobic®	1.1 m ³ /hr (5 gpm)	6.8 m ³ /hr (30 gpm)
6 x 28 Extra-Flow	1 m ³ /hr (5 gpm)	11 m ³ /hr (50 gpm)
8 x 20 Extra-Flow with XIND fiber	1 m ³ /hr (5 gpm)	11 m ³ /hr (50 gpm)
8 x 20 Extra-Flow SS with X40 fiber	1 m ³ /hr (5 gpm)	11 m ³ /hr (50 gpm)
8 x 40 Extra-Flow	7 m ³ /hr (30 gpm)	28 m ³ /hr (125 gpm)
8 x 80 Extra-Flow	7 m ³ /hr (30 gpm)	28 m ³ /hr (125 gpm)
10 x 28 Extra-Flow with X40 & X50 Fiber	10 m ³ /hr (44 gpm)	57 m ³ /hr (250 gpm)
10 x 28 Extra-Flow with XIND Fiber	10 m ³ /hr (44 gpm)	48 m ³ /hr (210 gpm)
14 x 28 Extra-Flow	16 m ³ /hr (70 gpm)	91 m ³ /hr (400 gpm)
14 x 40 Extra-Flow	16 m ³ /hr (70 gpm)	125m ³ /hr (550 gpm)

After calculating the minimum number of parallel trains, additional contactors can be added in series to obtain the desired dissolved gas concentration. The number of contactors in series will be a function of the required gas outlet and the maximum allowable system pressure drop. Typically 5 in series is the maximum. Performance is also improved with lower flow rates. If you reach the maximum desired pressure drop, you can also add additional parallel trains to achieve lower gas outlets and lower pressure drop.

2. Liquid-Stream Flow Configuration

The following are guidelines for designing the water process lines for a Liqui-Cel Extra-Flow or SuperPhobic® Membrane Contactor system. These guidelines take into consideration the contactor orientation. While liquids typically flow on the shell side of the contactor, some applications utilize lumen side liquid flow. Note that liquids should always flow on the shell side of the SuperPhobic Contactors.

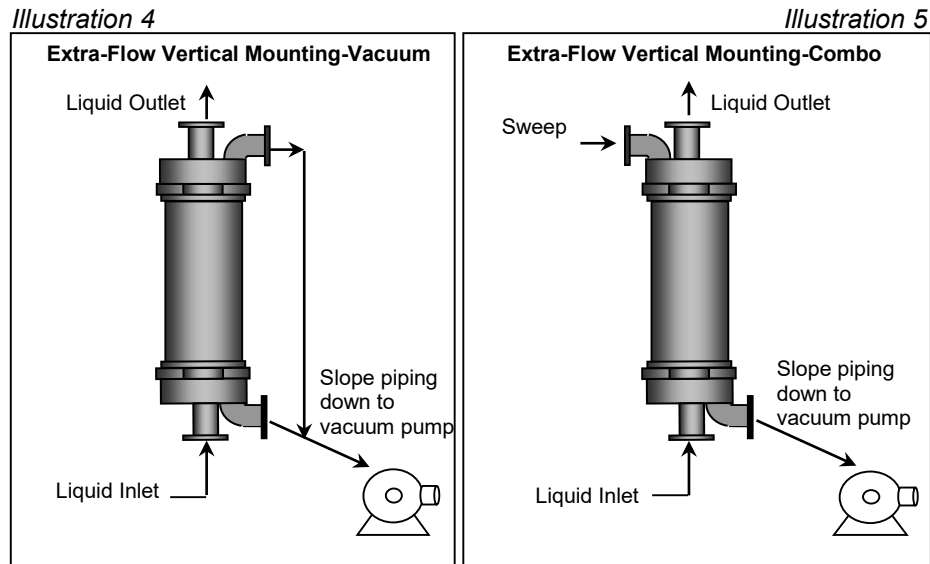
B. Vertical or Horizontal Mounting

- If the water pressure coming into the Liqui-Cel® Membrane Contactor system is greater than, or could be greater than, the maximum operating pressure, a pressure regulator is strongly recommended. For maximum pressure ratings refer to the appropriate data sheet or Section C, *Maximum Operating Temperature and Pressure Guidelines*, on pages 32 of this guide.
- If a pump is located downstream of the contactor system, an automatic on/off valve connected to the pump's motor is required. The valve should operate on a time delay with a slow open/close ramp.
- To avoid damage from water hammer, a rupture disc should be placed on the upstream side of the contactor system.
- Low-point drains, high-point vents, pressure indicators and temperature indicators should be included in the design.
- Gas must flow countercurrent to liquid for all contactors. Lower efficiencies will result if co-current flow is used.
- The contactors should not be exposed to freezing temperatures during periods of system shutdown.

Note: Horizontal mounting can be used for large contactors for ease of installation and replacement. For smaller contactors or smaller systems we recommend vertical mounting 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.

Vertical Mounting:

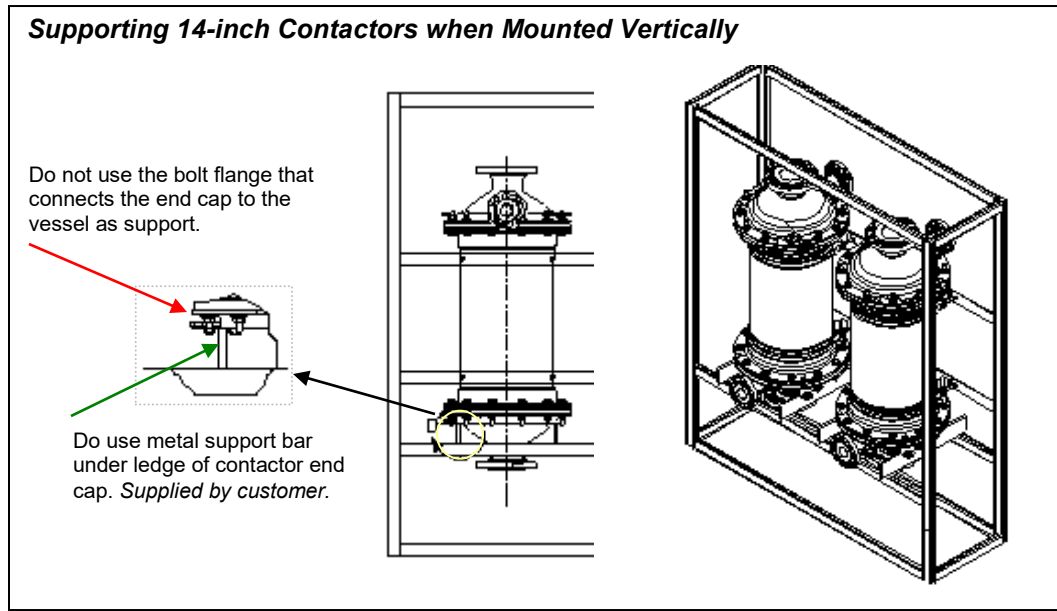
- If the contactors will be used intermittently vertical mounting is strongly recommended.
- The bottom gas port should be located higher than the suction port of the vacuum pump. This will allow for free drainage of condensed water to the vacuum pump. (**Illustration 4 and 5.**)



Additional Information for Vertically Mounting 14-inch Contactors

We recommend using our mounting kits and an additional steel bar support under the contactors to adequately support the full weight of the 14-inch contactors. Do not place the contactor load on the bolt flange that is used to secure the end caps onto the housing. Also, do not place the contactor load on the piping materials. Please refer to the vertical 14-inch vertical skid drawings on our website. These will provide you with more detailed information. A basic view of the metal support that is located under the bottom end caps is depicted below.

Illustration 6:



Horizontal Mounting:

- If the contactors will be used intermittently, we strongly recommend against horizontal mounting.
- 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 Illustration 7.)
- 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 inlet port of the vacuum pump to facilitate water drainage into the vacuum pump. (See Illustration 8.)

Illustration 7

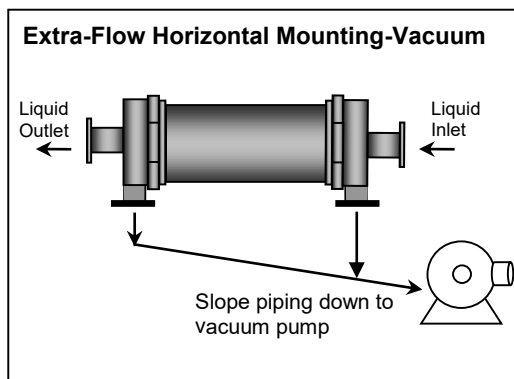
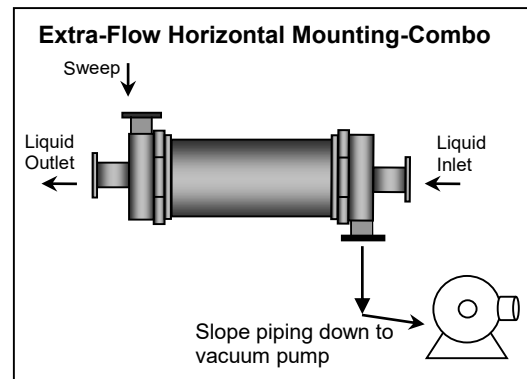


Illustration 8



C. Maximum Operating Temperature and Pressure Guidelines

There are three pressure ratings that operators and system builders should pay close attention to when operating and installing membrane contactors. There is a transmembrane pressure differential rating, a shell side (liquid) housing (or vessel) pressure rating and a lumen side (gas) housing pressure rating. The ratings for all three pressures for each product should be carefully reviewed prior to operation.

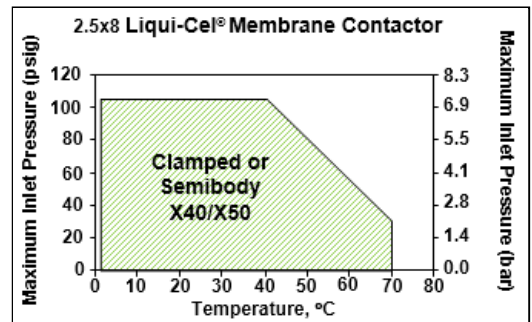
The transmembrane pressure differential (TMP) rating is the maximum difference in pressure from the outside to the inside of the fiber that the membrane can tolerate. If the shell side housing pressure rating is higher than the TMP rating, you can run at higher shell side liquid pressure so long as you maintain the TMP at or below its rating. On the other hand, if the TMP rating is higher than the shell side housing pressure rating, the shell side housing pressure will become the limiting factor during operation. **The maximum allowable pressure for each product, when used in their typical operating mode of combo or vacuum only, is listed in the shell side categories below.**
Note: Liquid pressure should always exceed gas pressure inside the contactor.

IMPORTANT NOTE: In most cases, liquid flows on the shell side (outside) of the contactor and the gas or vacuum phase is on the lumen side (inside) of the contactor. If conducting a pressurized gas test on the dry contactors to check for system and seal integrity during installation and first startup. **DO NOT** exceed the pressure limits given for the lumen side as gases will pass through the membrane during the test when liquid is not present. It is important not to over pressurize the gas side as the end caps have a lower pressure limit than the vessel in most cases.

Tables 6-12: Full Range of Membrane and Housing Pressure & Temperature Limit

Illustration 9

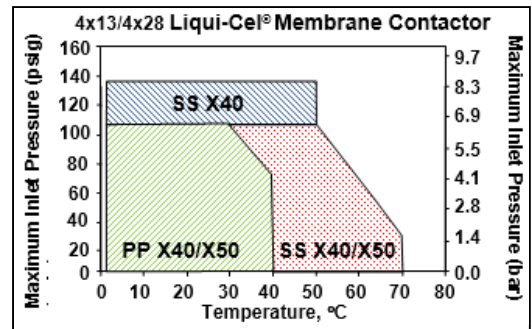
Table 6: 2.5 x 8 Pressure Rating Summary	
Shell side Pressure Limits*	Clamped or Semibody Housing
5-40 C	7.2 barg (105 psig)
70 C	2.1 barg (30 psig)
Lumen side Pressure Limits for Semibody (Unclamped Version)	
5 C	6.2 barg (90 psig)
15-25 C	4.8 barg (70 psig)
70 C	1.0 barg (15 psig)
Transmembrane Pressure Limits	
5-40 C	8.3 bard (120 psid)
70 C	3.1 bard (45 psid)



Graph based on vacuum only or combo operating mode.

* If no vacuum is used, 1.05 barg (15 psig) can be added to the pressures listed. **DO NOT** run liquid on lumenside for clamped version of this product.

Table 7: 4 x 13 and 4 x 28 Pressure Rating Summary			
Shell side Pressure Limits*	PP Housing (X40/X50 Membrane)	316 SS Housing X50 Membrane	316 SS Housing X40 Membrane
5-30 C	7.2 barg (105 psig)	7.2 barg (105 psig)	9.3 barg (135 psig)
40 C	5.2 barg (75 psig)		
5-50 C	N/A	2.1 barg (30 psig)	
70 C	N/A		
Lumen side Pressure Limits			
5-30 C	4.1 barg (60 psig)	6.2 barg (90 psig)	
40 C	2.1 barg (30 psig)		
40-50 C	N/A		
70 C	N/A	2.1 barg (30 psig)	
Transmembrane Pressure Limits		X50 Membrane	X40 Membrane
5-60 C		8.3 bard (120 psid)	10.3 bard (150 psid)
70 C		3.1 bard (45 psid)	3.1 bard (45 psid)



Graph based on vacuum only or combo operating mode.

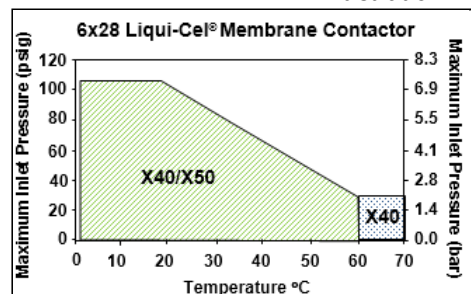
* If no vacuum is used, 1.05 barg (15 psig) can be added to the pressures listed. **Note:** The UltraPhobic I fiber in SuperPhobic® Contactors is limited to 5.2 barg (75 psig) at 25 C. The UltraPhobic II fiber in SuperPhobic® Contactors is limited to 7.2 barg (105 psig) at 25 C.

Table 8: 6 x 28 Pressure Rating Summary

Shell side Pressure Limits*	ABS Housing	
	X50 Membrane	X40 Membrane
5-25 C	7.2 barg (105 psig)	
60 C	2.1 barg (30 psig)	
70 C	Not Recommended	2.1 barg (30 psig)
Lumen side Pressure Limits		
5-25 C	4.1 barg (60 psig)	
Transmembrane Pressure Limit		
5-25 C	X50 Membrane	X40 Membrane
5-25 C	8.3 bard (120 psid)	
70 C		3.1 bard (45 psid)

* If no vacuum is used, 1.05 barg (15 psig) can be added to the pressures listed.

Illustration 11



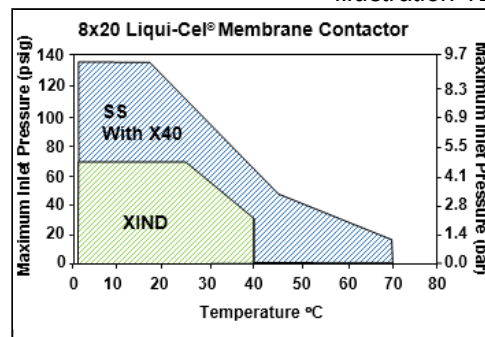
Graph based on vacuum or combo operating mode.

Table 9: 8 x 20 Pressure Rating Summary

Shell side Pressure Limits*	PVC Housing with XIND Membrane	SS Housing with X40 Membrane
	5-25 C	4.8 barg (70 psig)
40 C	2.1 barg (30 psig)	
50 C		3.1 barg (45 psig)
70 C		1.1 barg (15 psig)
Lumen side Pressure Limits		
15-25 C	1.0 barg (14.7 psig)	5.2 barg (75 psig)
Transmembrane Pressure Limits		
5-40 C	4.8 bard (70 psid)	9.3 bard (135 psid)
70 C	N/A	3.1 bard (45 psid)

* If no vacuum is used, 1.05 barg (15 psig) can be added to the pressures listed.

Illustration 12



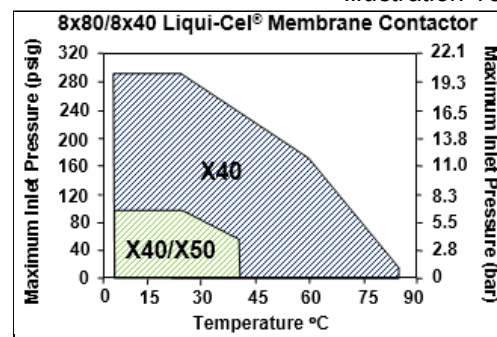
Graph based on vacuum or combo operating mode.

Table 10: 8 x 40 and 8 x 80 Pressure Rating Summary

Shell side Pressure Limits*	FRP with X40 Membrane
	5-25 C
60 C	12.0 barg (175 psig)
85 C	1.0 barg (15 psig)
Lumen side Pressure Limits	
15-25 C	2.1 barg (30 psig)
Transmembrane Pressure Limits	
5-25 C	X40 Membrane
5-25 C	20.7 barg (300 psid)
60 C	13.1 barg (190 psid)

* If no vacuum is used, 1.05 barg (15 psig) can be added to the pressures listed.

Illustration 13



Graph based on vacuum or combo operating mode.

Operating Pressure and Temperature Guidelines for 10 x 28, 14x28, 14x40, 8x40, 8x80

The 10 x 28 pressure ratings are summarized below. There are two sets of pressure limits specified for the 10 x 28 Contactor. The Pressure Equipment Directive (PED) 97/23/EC put forth by the European Union has specific guidelines that place devices in various hazardous classifications. We chose to limit some pressure ratings in our 10-inch device for sales into the European Union (EU) because the lower pressures do not affect our primary applications and uses. These limits keep them in a lower hazard classification and eliminate additional testing and fabrication costs associated with higher ratings.

Pressure limits only apply to the use of dangerous liquids or gases in 10-inch products sold into European Union Member States. All other countries are free to operate to the higher pressures summarized in the table below.

MiniModule™, 2.5-inch, 4-inch, 6-inch, 8-inch and 10-inch Industrial products do not require CE Marking per the PED 97/23/EC. Instead they are manufactured with Sound Engineering Practices (SEP).

Table 11: 10 x 28 Pressure Rating Summary Rest of World outside EU (see below for EU limits)

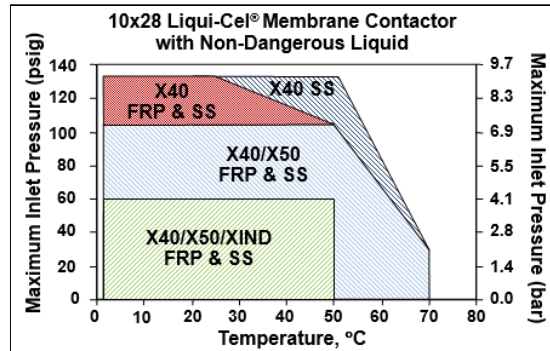
Shell side Pressure Limits*	FRP Housing			316 SS Housing	
	X50 Membrane	X40 Membrane	XIND Membrane	X50 Membrane	X40 Membrane
5-25 C	7.2 barg (105 psig)	9.3 barg (135 psig)	4.1 barg (60 psig)	7.2 barg (105 psig)	9.3 barg (135 psig)
50 C	7.2 barg (105 psig)	7.2 barg (105 psig)	4.1 barg (60 psig)	7.2 barg (105 psig)	9.3 barg (135 psig)
70 C	2.1 barg (30 psig)	2.1 barg (30 psig)	N/A	2.1 barg (30 psig)	2.1 barg (30 psig)
Lumen side Pressure Limits	FRP Housing		316 SS Housing		
	X50/X40 Membrane	XIND Membrane	X50 Membrane	X40 Membrane	
5-50 C	6.2 barg (90 psig)	5.2 barg (75 psig)	8.3 barg (120 psig)	9.0 barg (130 psig)	
70 C	2.1 barg (30 psig)	N/A	2.1 barg (30 psig)		
Transmembrane Pressure Limit	X50 Membrane	XIND Membrane	X40 Membrane		
5-50 C	8.3 barg (120 psid)	5.2 barg (75 psid)	10.3 barg (150 psid)		
70 C	3.1 barg (45 psid)	Not applicable	3.1 barg (45 psid)		

European Union Member States - Pressure Limits

	Shell side (Liquid)	Lumen side (Gas)			Membrane	
	FRP or 316 SS	FRP (X50/X40)	FRP (XIND)	316 SS	X50 Membrane	X40 Membrane
Dangerous Liquid	10.0 barg (145 psig)	N/A		N/A	8.3 barg (120 psig)	10.3 barg (150 psig)
Non-Dangerous Liquid	10.3 barg (150 psig)	N/A		N/A	8.3 barg (120 psig)	10.3 barg (150 psig)
Dangerous Gas	N/A	4.7 barg (68 psig)	2.3 barg (33 psig)	4.7 barg (68 psig)	8.3 barg (120 psig)	10.3 barg (150 psig)
Non-Dangerous Gas	N/A	6.2 barg (90 psig)	4.1 barg (60 psig)	9.0 barg (130 psig)	8.3 barg (120 psig)	10.3 barg (150 psig)

* If no vacuum is used, 1.05 barg (15 psig) can be added to the pressures listed.

Illustration 14



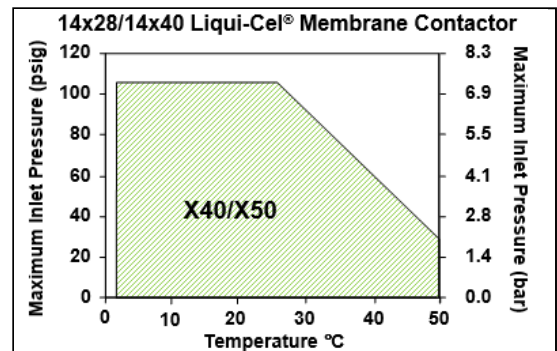
Graph based on vacuum or combo operating mode.

Table 12: 14 x 28 and 14 x 40 Pressure Rating Summary - EU and Rest of World

Shell side Pressure Limits*	PVC Housing X50/X40 Membrane
5-25 C	7.2 barg (105 psig)
50 C	2.1 barg (30 psig)
Lumen side Pressure Limits	
5-25 C	4.1 barg (60 psig)
50 C	2.1 barg (30 psig)
Transmembrane Pressure Limits	
5-25 C	8.3 barg (120 psig)
50 C	3.1 barg (45 psig)

* If no vacuum is used, 1.05 barg (15 psig) can be added to the pressures listed.

Illustration 15



Graph based on vacuum or combo operating mode.

D. Contactor Weights for System Fabrication:

The system framework should be designed to support the maximum liquid-full (shell side) weights of the contactors. The weights listed below are for one contactor so the total number of contactors will need to be taken into consideration when designing the skid support structure. Also note that these are maximum weights. Some housing options may weigh less. See product data sheet for more details.

Table 13: Contactor Weights

Product	Housing Material	Dry Weight Kg. (lbs.)	Liquid Full Weight Kg. (lbs.)
2.5 x 8	Polypropylene	0.5 (1.1)	0.9 (2.0)
4 x 13	Polypropylene	2.6 (5.8)	4.9 (10.7)
4 x 13	Stainless Steel	4.9 (10.7)	7.4 (16.4)
4 x 28	Polypropylene	4.1 (9.0)	6.8 (15.0)
4 x 28	Stainless Steel	6.9 (15.0)	9.6 (21.0)
6 x 28	ABS	10.4 (23.0)	17.1 (37.7)
8 x 20	PVC	12.7 (27.9)	19.3 (42.7)
8 x 20	SS	37.2 (82.1)	43.6 (96.1)
8 x 40	Fiber Reinforced Plastic (FRP)	35.4 (78.0)	49.9 (110.0)
8 x 80	Fiber Reinforced Plastic (FRP)	52.2 (115.0)	88.9 (196.0)
10 x 28	Fiber Reinforced Plastic (FRP)	33 (73.0)	57 (125.0)
10 x 28 IND	Fiber Reinforced Plastic (FRP)	33 (73.0)	57 (125.0)
10 x 28	Stainless Steel with ANSI/JIS connection	76 (168.0)	99 (218.0)
10 x 28	Stainless Steel with Sanitary connection	81 (177.0)	107 (235.0)
14 x 28	Engineering thermoplastic	53.0 (118)	89.0 (196.0)
14 x 40	Engineering thermoplastic	64.0 (141.0)	116.0 (256)

E. Filtration Requirements

The inlet liquid and gas streams should be pre-filtered for suspended particulate matters. The proper filtration rating/arrangement will depend on the water source and in many instances particulate filtration alone will not provide sufficient protection from membrane's surface fouling or plugging of shell side, both of which can negatively impact gas removal efficiency. Table 14 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 contactors and restrict the flow through the contactor system. Additionally, some dissolved compounds such as hardness and silica found in well, surface and city water will not be captured by any particulate filter and could potentially deposit on membrane's surface (surface scaling). DI water in combination with recommendations in Table 15 will provide the best water source for trouble free operation.

Table 14: General Particulate Filtration Guidelines

Liquid stream (shell side)	5 microns 2 microns when installed downstream of a carbon bed
Gas stream (Lumen side)*	0.2 micron for high-purity applications 1.0 micron is sufficient for industrial applications

*oil and aerosol-free

F. Membrane Fouling

When a 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 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 contactor's removal efficiency will drop. This process is reversible by cleaning the contactor with an acid solution such as 3% w/w ortho-phosphoric acid solution (refer to the Liqui-Cel® Membrane Contactor [Cleaning 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 2 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 Liqui-Cel Membrane Contactors are installed upstream of RO membranes, a cleaning cycle is also recommended in order to prevent fouling of the Liqui-Cel Membrane Contactor. Please refer to the Liqui-Cel Membrane Contactor [Cleaning Guidelines](#) available on-line at www.liqui-cel.com or from your 3M representative.

G. System Instrumentation Recommended

Pressure gauges

- Near contactor water inlet, isolation valve optional
- Near contactor water outlet, isolation valve optional
- Nitrogen inlet, isolation valve optional
- After nitrogen flowmeter (compound gauge), isolation valve optional
- Vacuum line pressure, isolation valve optional
- Vacuum service water near pump connection, isolation valve optional

Flowmeters

- Nitrogen sweep
- Process inlet

Pressure regulator

- Nitrogen pressure regulator, which brings the line pressure down

Valves

- Process stream
 - Isolation valves
 - Inlet manual flow control valve
 - Pressure relief valve
 - Drain valves between contactors
- Vacuum pump
 - Suction check valve
- Vacuum service water
 - Check valve
 - Needle valve
 - Solenoid
 - Inlet shut-off
- Nitrogen
 - Shut-off
 - Manual flow control valve
 - Pressure relief valve if required

Pressure switches

- Process inlet high pressure switch to shut down or warn operator
- Vacuum line high pressure switch to warn operator

Temperature measurement

- Process liquid
- Nitrogen at flowmeter, optional
- Vacuum service water feed, optional

H. Warnings of Misuse

Avoid the following: water hammer, over-pressurization, dropping of contactors and over-torquing the end cap clamp bolts, if applicable. Using power driven tools to tighten nuts can produce excessive friction and increase the risk of thread damage. It is also important to follow recommendations when supporting 14-inch contactors in a system. The bolt flange that attaches the end caps to the vessel should not be used to support the weight of the contactor.

Also note that if membrane failure occurs, liquid could enter the gas side. Though this would be extremely rare, a pressure-limiting device downstream of the gas outlets would protect downstream equipment such as vacuum pumps, blowers, etc. Also note that the membrane will allow gases to freely pass from one side of membrane to the other side if water is not present on one side of the membrane. Therefore, any system pressure tests with compressed gas should be used only to the maximum listed gas-side pressures as listed in Tables 7-13 of this guide.

V. System Design Requirements for Obtaining Low Levels of Dissolved Oxygen

WARNING

To reduce the risks associated with explosion:

- DO NOT exceed maximum operating pressure or temperature limits.
- DO NOT exceed maximum liquid temperature or pressure limits.
- Ensure both gas/vacuum ports are not closed during operation.
- Over-pressurization of liquid and gas should be prevented by the installation of proper pressure relief valves.

To reduce the risks associated with hazardous voltage:

- Ensure electrical connections are properly grounded.
- Always use a grounded power supply of the appropriate voltage matching the system's vacuum pump or blower voltage with a 15 amp fuse protection and a local disconnect switch.
- Always verify the appropriate electrical connection with your local electrical code and replace plug as necessary.

CAUTION

To reduce the risks associated with impact:

- Always make sure the contactor is properly secured.

To reduce the risks associated with damaging the membrane contactor:

- For all 2.5x8-inch, 4-inch and 10-inch membrane contactors, lumen side pressure should never exceed shell side pressure during cleaning.
- Do not expose the membrane to air when liquid or gas temperatures exceed 35° C (95° F).
- All plastic port extensions should be supported to prevent bending of extensions under excessive piping loads.

NOTICE

- Avoid contacting membrane to surfactants or solvents to prevent membrane wet-out.
- Do not expose membrane to oxidizing species such as ozone, chlorine, hydrogen peroxide, peracetic acid, etc. to prevent membrane oxidation.
- Filtered, de-chlorinated, and deionized water is recommended for mixing cleaning solutions. Water containing metals such as Mg, Fe, Al, and SiO₂ may precipitate on to the membrane surface when there is a pH shift in the water.

To ensure maximum performance, it is important to follow the instructions below to minimize the chances of oxygen contamination or in-leakage from the atmosphere into the system. As specified by the standard product performance warranty, customer compliance with the following conditions is strongly recommended.

- Do not use threaded connections in the sweep gas or vacuum piping. All-welded systems are recommended. When service connections are required, flanged connections or specially designed vacuum fittings are recommended.
- The system must be designed and installed so that there is no air in-leakage.
- Performance results are dependent upon sweep gas purity. For units targeting <5ppb residual dissolved oxygen (DO) concentration, the minimum purity nitrogen required is 99.99%. For units targeting < 1ppb residual DO concentration, the minimum purity nitrogen required is 99.995%. Both purity levels are based on molar compositions.
- The sample lines used to measure DO concentrations must be constructed of materials that are impermeable to gases (e.g. PEEK or stainless steel) to prevent contamination from atmospheric oxygen. Do not use tubing made of permeable materials such as PFA, PTFE, Tygon, Polyurethane, Nylon, polypropylene, polyethylene, etc.
- Residual dissolved oxygen concentrations in water of < 5ppb must be measured using an accurately calibrated dissolved-oxygen analyzer. The instrument calibration, operation and measurement conditions must be according to Instrument manufacturer specifications and standards.
- Residual dissolved oxygen measurements must be made as close as practically possible to the outlet of the final contactor(s).
- Adequate vacuum pump capacity is critical for systems designed with vacuum. For vacuum pump sizing purposes, a design safety factor of 20 to 25% is recommended. Ideally, the vacuum pump capacity should be large enough to achieve > 27 in. Hg gauge vacuum (< 75 mm Hg. absolute pressure under the maximum gas loading condition. Lowering the absolute vacuum pressure enhances degassing performance.
- An important part of a degassing system design/operation includes proper selection of the sample lines and the oxygen instrumentation and calibration. All Liqui-Cel® Membrane Contactors are subject to stringent quality control/assurance (QA/QC) procedure before they are shipped to a customer site. Oxygen removal and pressure drop measurements and fiber leakage testing are all included in QC procedure. The possibility of a contactor being shipped that has lower performance than the minimum accepted criteria due to a membrane or manufacturing defect is rare. Poor system performance during startup is generally caused by an air leak into the system or a poorly operated or calibrated oxygen analyzer. Check equipment and sample lines for leaks.
- Avoid fittings not rated for vacuum service when building a degasification unit that operates under vacuum-only or sweep-assisted vacuum mode. These fittings can be a source of air leaks in the degassing system.

VI. Startup, Standby and Shutdown Procedures

WARNING

To reduce the risks associated with explosion:

- DO NOT exceed maximum operating pressure or temperature limits.
- DO NOT exceed maximum liquid temperature or pressure limits.
- Ensure both gas/vacuum ports are not closed during operation.
- Over-pressurization of liquid and gas should be prevented by the installation of proper pressure relief valves.

To reduce the risks associated with hazardous voltage:

- Ensure electrical connections are properly grounded.
- Always use a grounded power supply of appropriate voltage matching the system voltage with fuse protection and a local disconnect switch.
- Always verify the appropriate electrical connection with your local electrical code and replace plug as necessary.

CAUTION

To reduce the risks associated with hot surfaces:

- DO NOT touch the blower during operation.
- Always direct blower discharge away from the operator.
- Do not touch the membrane contactor during a hot sanitization cycle and allow enough time for the surface of the membrane contactor to cool.

To reduce the risks associated with impact:

- Always make sure the contactor is properly secured.

To reduce the risks associated with damaging the membrane contactor:

- For all 2.5x8-inch, 4-inch and 10-inch membrane contactors, lumen side pressure should never exceed shell side pressure during cleaning.
- Do not expose the membrane to air when liquid or gas temperatures exceed 35° C (95° F).
- All plastic port extensions should be supported to prevent bending of extensions under excessive piping loads.

NOTICE

- Avoid contacting membrane to surfactants or solvents to prevent membrane wet-out.
- Do not expose membrane to oxidizing species such as ozone, chlorine, hydrogen peroxide, peracetic acid, etc. to prevent membrane oxidation.
- Filtered, de-chlorinated, and deionized water is recommended for mixing cleaning solutions. Water containing metals such as Mg, Fe, Al, and SiO₂ may precipitate on to the membrane surface when there is a pH shift in the water.

A. General startup instructions for the liquid phase

Note: Both gas/vacuum ports should not be closed during operation. These ports provide a safety vent in the 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 contactor never exceed the maximum operating limits (see pages 32-34).
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 and vacuum phase

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

Sweep Gas Mode

Regulate the gas pressure entering the contactor at ≤ 10 psig (0.7 bar, 0.7 kg/cm²) by adjusting the appropriate valve in the gas delivery system.

1. Set the recommended total sweep flow rate by adjusting the appropriate valves. See the sweep guidelines for typical sweep gas flow rate ranges in table 1.
2. Introduce fresh sweep gas into each contactor.

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 & 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.

Sweep Gas with Vacuum (Combo) Mode

1. Introduce fresh sweep gas into each contactor.
2. Apply vacuum as described in the vacuum section below.
3. Regulate the gas pressure entering the contactor at ≤ 1 psig (0.07 bar, 0.07 kg/cm²) by adjusting the appropriate valve on the gas delivery system.
4. Set the recommended total sweep flow rate by adjusting the appropriate valve. See sweep guidelines for typical sweep gas flow rate ranges in Table 3.

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.

Vacuum Only Mode

1. Start vacuum pump following vacuum pump manufacturer's instructions.
2. Apply vacuum to the contactor by opening the appropriate valve.
3. Adjust absolute gas pressure on the vacuum side to the desired level at the vacuum port on the contactor.

Blower in suction mode with atmospheric air as sweep gas for CO₂ removal

1. Start blower in suction mode operation.
2. Open isolation valve (if applicable).
3. Close relief valve.

NOTE: The start-up procedure for 8x40 and 8x80 contactors is different.

C. Shutdown Procedure

1. 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 contactor after shutdown.
2. Mode:
 - a. Sweep-gas mode using nitrogen or other inert gas:
 - It is advisable to let the nitrogen (or CO₂ or other inert gas) purge the system for 1 hour.
 - If possible, maintain a low gas flow during the shutdown period.
 - b. Air sweep or air combo or vacuum-only mode:
 - Close the gas inlet valve(s) (if applicable).
 - Shut off the vacuum pump and close the gas outlet valves (if applicable). Care must be taken to prevent backflow of any service liquid or lubricants from the vacuum pump to contactors.
 - To prevent biological growth it is recommended that contactors be stored dry. If dry storage is not at all possible or practical, contactors may be stored with the liquid side filled with a biocide (ideally, a non-oxidizing biocide such as DBNPA) for the duration of the shutdown period. Monitor the biocide level to maintain its effectiveness. In some situations use of preservatives such as sodium sulfite or metabisulfite is acceptable.
 - c. Blower in suction mode for CO₂ removal
 - Open relief valve.
 - Close isolation valve (if applicable).
3. If your shutdown period will be less than 24 hours, we recommend leaving sweep or vacuum on. This will keep the lumens purged of any condensed liquid.

D. Startup after Shutdown Procedure

When startup occurs after a shutdown period, water that condenses inside hollow fibers must be removed.

- Open the vacuum inlet valve (if applicable) and start the vacuum pump.
- Open the gas outlet valves.
- Open the air sweep inlet valves (if applicable).
- Follow procedure outlined in section VI-B above.

Shutdown Procedure for intermittent operation

The shutdown procedure described in sections VI A-D is typically valid for short term stoppage of Liqui-Cel® systems. If the Liqui-Cel system is operated only for short periods of time and then sits water-full idly for long periods of time, a separate **procedure to prepare contactors for standby mode** is recommended. Preparing contactors for standby mode implies that the contactors will not be operated for significant lengths of time, typically 7 days or longer.

Procedure to prepare contactors for standby mode:

If it is known beforehand that the Liqui-Cel system will be operated only intermittently, with long shut downs in between operation, it is highly recommended that the Liqui-Cel system be designed specifically with intermittent operation in mind. Keep in mind that the best way to preserve Liqui-Cel contactors is to store them dry, which is distinctly different from the way hydrophilic filtration membranes are normally preserved.

Since Liqui-Cel contactors are best stored dry, it is necessary to design the system such that contactors can be drained and dried before long storage. To facilitate the draining of contactors when not in use, it is preferable to design the system with contactors mounted vertically rather than horizontally, to take advantage of gravity, irrespective of the strip mode (vacuum, sweep, or combo). See figures 1 & 2. In addition, system piping should be done such that (a) liquid flows upward and gas or vacuum flow downward within the contactor, (b) drain valve(s) be installed at the lowest point in the system, and (c) vent valve(s) be installed at the highest point in the system.

Recommended steps to prepare contactors for standby mode:**System designed for operation in vacuum-only mode (Figure 10):**

1. Stop water flow through contactors and de-pressurize contactors.
2. Close the valve at water inlet line but keep the valve at water outlet open.
3. Close valve in the piping to vacuum pump and open the vent valve above the contactors.
4. Open the drain valve and allow water from the contactors to drain out under gravity.
5. Keep drain valve open for a few more additional minutes till water stops dripping out of the drain valve.
6. Connect dry, 3um filtered compressed air to the vent valve and apply air pressure through the vent valve at less than 30 psi to force out any bulk water on the gas side of membrane that did not drain under gravity and also most of the bulk water out through the drain port and the water outlet line. After a few minutes close the drain valve so that pressurized air enters the system through vent valve and leaves through water outlet line.
7. Allow compressed air to flow through the contactors for at least one hour to effect partial drying of contactor.
8. Close the vent valve and the water outlet valve. At this point, the contactors are essentially free of liquid water and are isolated from outside atmosphere.
9. The contactors are now in standby mode and are ready for long term storage till the system is restarted at a later date.

System Restart Procedure:

When the Liqui-Cel® system is ready to be brought back online, follow the steps below:

1. Open the drain valve, then the vent valve.
2. Connect dry, 3um filtered compressed air to the vent valve and apply air pressure through the vent valve at less than 30 psi to force out any water vapor that may have condensed inside the contactors during the standby period.
3. Allow compressed air to flow through the contactors for about one hour.
4. Close the vent valve, then the drain valve.
5. Open the water inlet and water outlet valves.
6. At this time, the contactors are ready for full operation.

System designed for operation in air-combo or N2-combo mode (Figure 11):

1. Stop water flow through contactors and de-pressurize contactors.
2. Close the valve at water inlet line but keep the valve at water outlet open.
3. Close valve in vacuum line and close sweep gas supply valve.
4. Open the vent valve.
5. Open the drain valve and allow water from the contactors to drain out under gravity.
6. Keep drain valve open for a few more additional minutes till water stops dripping out of the drain valve.
7. Connect dry, 3um filtered compressed air to the vent valve and apply air pressure through the vent valve at less than 30 psi to force out any bulk water on the gas side of membrane that did not drain under gravity and also most of the water in the water outlet line.
8. Allow compressed air to flow through the contactors for about one hour to effect partial drying of contactor.
9. Close the vent valve, the drain valve, and the water outlet valve. At this point, the contactors are essentially free of liquid water and are isolated from outside atmosphere.
10. The contactors are now in standby mode and are ready for long term storage till the system is restarted at a later date.

System Restart Procedure:

When the Liqui-Cel® system is ready to be brought back online, follow the steps below:

1. Open the drain valve, then the vent valve.
2. Connect dry, 3um filtered compressed air to the vent valve and apply air pressure through the vent valve at less than 30 psi to force out any water vapor that may have condensed inside the contactors during the standby period.
3. Allow compressed air to flow through the contactors for about one hour.
4. Close the vent valve, then the drain valve.
5. Open the water inlet and water outlet valves.
6. At this time, the contactors are ready for full operation.

Figure 10. Generic P & ID for Vacuum Mode – Vertical (option for air drying included to prepare system for standby mode)

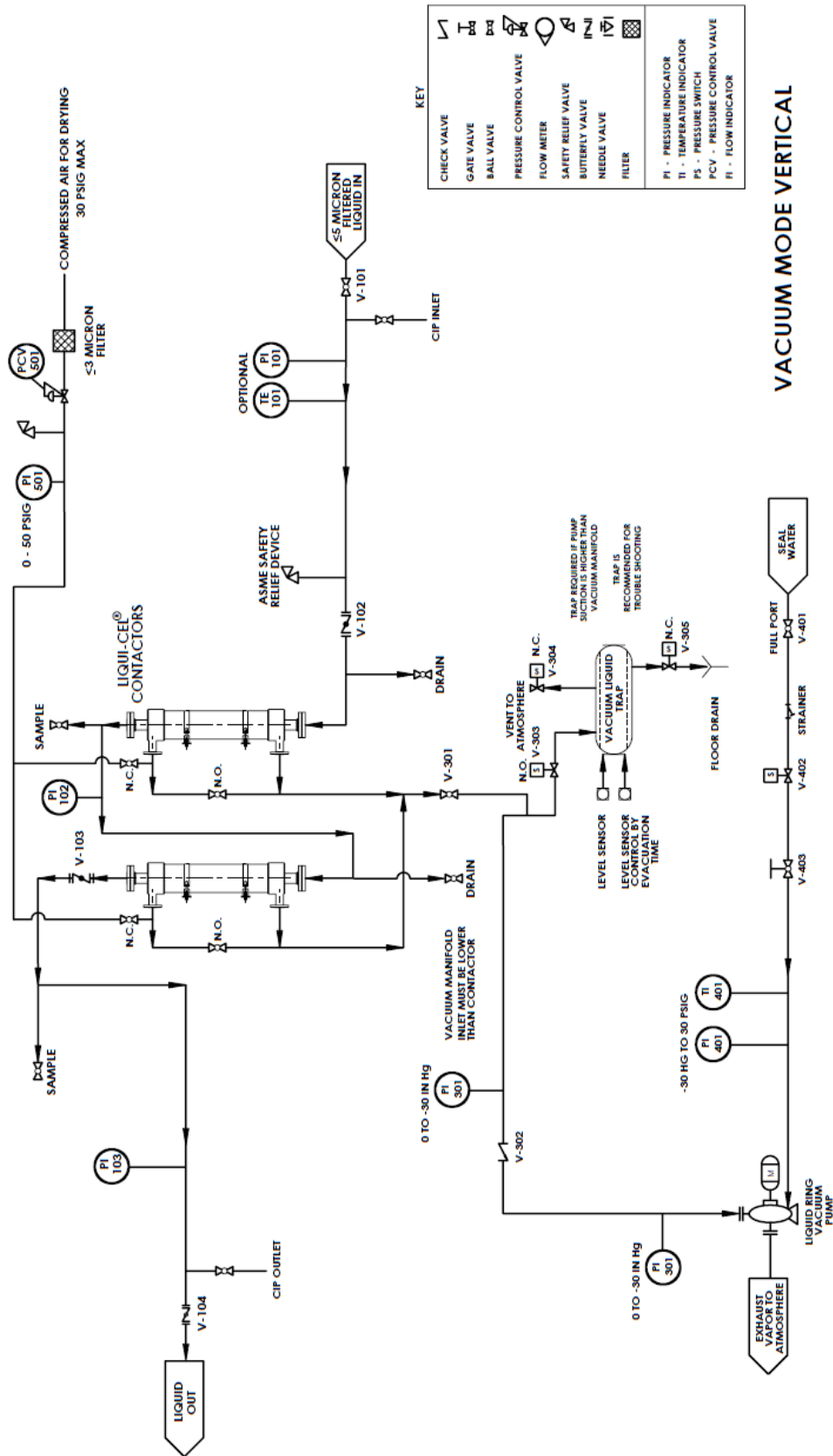
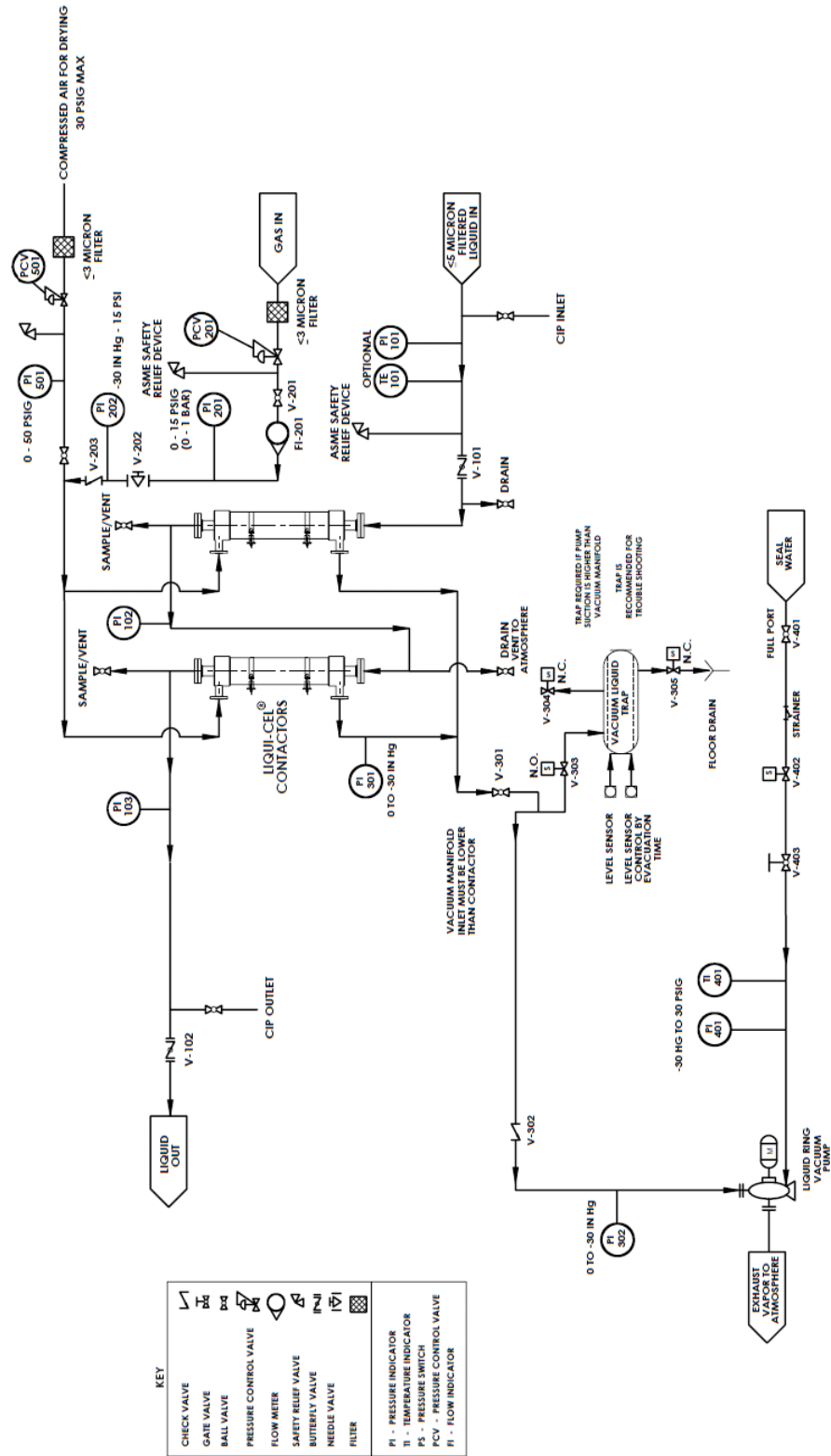


Figure 11. Generic P & ID for Combo Mode Vertical (option for air drying included to prepare system for standby mode)



VII. Maintenance

WARNING

To reduce the risks associated with explosion:

- DO NOT exceed maximum operating pressure or temperature limits.
- DO NOT exceed maximum liquid temperature or pressure limits.
- Ensure both gas/vacuum ports are not closed during operation.
- Over-pressurization of liquid and gas should be prevented by the installation of proper pressure relief valves.

To reduce the risks associated with hazardous voltage:

- Ensure electrical connections are properly grounded.
- Always use a grounded power supply of appropriate voltage matching the system voltage with fuse protection and a local disconnect switch.
- Always verify the appropriate electrical connection with your local electrical code and replace plug as necessary.

Maintaining a system performance Log is recommended for Liqui-Cel® Membrane Contactors. We suggest a weekly or bi-weekly check of the system to insure the performance is acceptable. For warranty purposes the performance log should record critical information as shown in the example below.

Date	Operator	Water flow rate	Water pressure Into and out of contactors	Vacuum level in contactors	Sweep gas flow rate into contactors	Water and gas inlet temperatures	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 contactors. Cleaning and lumen purging are typically the only maintenance required. See the 3M Cleaning Guide available online at www.liqui-cel.com.

VIII. Expected Service Life

WARNING

To reduce the risks associated with explosion:

- DO NOT exceed maximum operating pressure or temperature limits.
- DO NOT exceed maximum liquid temperature or pressure limits.
- Ensure both gas/vacuum ports are not closed during operation.
- Over-pressurization of liquid and gas should be prevented by the installation of proper pressure relief valves.

To reduce the risks associated with hazardous voltage:

- Ensure electrical connections are properly grounded.
- Always use a grounded power supply of appropriate voltage matching the system voltage with fuse protection and a local disconnect switch.
- Always verify the appropriate electrical connection with your local electrical code and replace plug as necessary.

The expected replacement schedule provided below is intended as a guideline when products are used in accordance with all handling, storage, operating and any other recommendations found in this guideline and in the start-up guide. Replacement period guidelines assume RO permeate quality water, except where noted.

Product	Description/Notes	Expected Replacement Period
2.5 x 8, 4 x 13, 4 x 28, and 6 x 28 membrane contactors		Every 5 years
8 x 20 membrane contactor	PVC Housing	3-5 years
	SS Housing	5-7 years
8 x 40 and 8 x 80 membrane contactors	After Sulfate Reduction Unit (SRU) or RO permeate Water	5 years
	When operated in 5 um filtered, zero chlorine seawater at a temperature < 25 C	3 years
10 x 28 membrane contactors	PVDF-lined (High Purity) FRP and SS	10 years
10 x 28 Industrial	FRP (without PVDF-lining)	5 years
14 x 28 and 14 x 40		5 years

Refer to the appropriate data sheet and Tables 6-12 for maximum operating limits of pressure and temperature for contactors. No warranty is implied.

IX. 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 1°C/minute (1.8°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.

X. Contactor Storage & Operating Environment

The Membrane Contactor that you have purchased can be damaged through improper handling and storage. The following guidelines are intended to provide a framework for successful storage of these contactors. If you have any questions, please contact your 3M representative.

Handling: Proper handling of contactors is critical. Care must be taken not to hit or jar (shock) the contactor to minimize the possibility of internal damage. It is recommended that the contactors be stored in a dry, heat-sealed plastic bag or shrink wrap material [0.08 mm (0.003 in.) wall thickness] in their original box to prevent the introduction of contaminants into the contactor.

Important Note: All plastic port extensions should be supported to prevent bending of extensions under excessive piping loads.

Temperature: Store the contactor dry in their original boxes at temperatures not to exceed 49° C (120° F). Contactors stored at very low temperatures < 5° C (41° F) should be allowed to equilibrate to room temperature prior to introducing water.

Humidity: It is recommended that contactors be stored at low to moderate humidity levels (< 60% relative humidity). Humidity will not affect the components of the contactor but exposure at high humidity levels may affect the integrity of the cardboard boxes.

Storage: Store the membrane contactors in the horizontal position. 10x28-inch membrane contactors with stainless steel housings are packaged in wooden crates. 14x28-inch, 10x28-inch with FRP housings, 8x20-inch and 6x28-inch membrane contactors are packaged in cardboard boxes. 8x40 inch and 8x80-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. Care should be taken to secure the membrane contactors and containers to ensure stability and to avoid any possible injury resulting from falling, leaning or any other accident.

Shelf Life: Membrane samples from contactors stored for 4 years (room temperature, low to moderate humidity, heat-sealed bag but not stored in a box) have shown no changes in physical properties (hollow fiber tensile strength and elongation).

Exposure to Sunlight: Contactors should not be stored where they are exposed to direct sunlight. Contactors should always be stored in sealed bags or shrink wrap material and in the original box or other opaque box.

XI. Contactor Sanitizing, Cleaning and Clean-in-Place

Refer to the Liqui-Cel® Membrane Contactor Cleaning Guidelines document available in the Technical Support Section on our website, www.liqui-cel.com, or from your 3M representative.

XII. Chemical Compatibility

For general guidelines, refer to the Liqui-Cel Membrane Contactor Chemical Resistance Guide available in the Technical Support Section on our website, www.liqui-cel.com, or from your 3M representative.

XIII. Cartridge Installation

For a detailed description, refer to the Liqui-Cel Membrane Contactor Assembly and Disassembly Instructions available in the Technical Support Section on our website, www.liqui-cel.com, or from your 3M representative.

XIX. Troubleshooting

Problem Description	Probable Cause	Corrective Action
Outlet dissolved gas concentration above specification or low performance after use.	<ul style="list-style-type: none"> ▪ Membrane contamination/fouling. 	<ul style="list-style-type: none"> ▪ Clean contactor. Refer to Cleaning Guidelines.
	<ul style="list-style-type: none"> ▪ Dust covers used in shipping may not have been removed. 	<ul style="list-style-type: none"> ▪ Verify shipping dust plugs, cap covers, and/or shrink wrap are removed from all ports before bolting the contactors into the system.
	<ul style="list-style-type: none"> ▪ Sweep gas contaminated. 	<ul style="list-style-type: none"> ▪ Verify sweep gas purity level.
	<ul style="list-style-type: none"> ▪ Insufficient sweep gas flow rate. 	<ul style="list-style-type: none"> ▪ Leakage of sweep gas from supply lines.
	<ul style="list-style-type: none"> ▪ Uneven sweep gas flow rate in individual contactors. 	<ul style="list-style-type: none"> ▪ Measure sweep gas flow rate in individual contactors.
	<ul style="list-style-type: none"> ▪ Air leaks in sweep or vacuum lines. 	<ul style="list-style-type: none"> ▪ Tighten gas side flange connections. ▪ Pressurize gas line and monitor to test for leaks. <ul style="list-style-type: none"> – 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. <ul style="list-style-type: none"> – Stop gas flow and operate in Vacuum only mode. Record conditions and outputs in sweep only mode. – Stop vacuum pump, open vacuum manifold and start gas flow. Record conditions and outputs in sweep only mode. ▪ Contact 3M representative.
	<ul style="list-style-type: none"> ▪ Low vacuum level. <p>Air leaks in the vacuum system.</p>	<ul style="list-style-type: none"> ▪ Ensure that the vacuum system is sized correctly and that the vacuum manifold is sized to handle vapor 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 line 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. <ul style="list-style-type: none"> – Does the vacuum line slope down from contactor to vacuum? If no, re pipe per page 30-31. – 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 is a normal occurrence, insulate vacuum manifold. ▪ Install larger capacity vacuum pump. Contact a 3M representative first.

XIX. Troubleshooting (Continued)

Problem Description	Probable Cause	Corrective Action
Outlet dissolved gas concentration above specification or low performance after use.	<ul style="list-style-type: none"> ▪ Condensation in contactor or vacuum lines. 	<ul style="list-style-type: none"> ▪ If contactor has been sitting wet while not in operation, there may be water condensation in the lumen. <ul style="list-style-type: none"> – Remove condensate inside of the fibers with a gas purge following procedure outlined in section VI-B. – Continue to sweep gas at high rate until no water drips from the gas exit port. – If the water drip continues for several minutes, contact a 3M Representative. ▪ Look for water accumulation in vacuum pipe. <ul style="list-style-type: none"> – Does vacuum line slope down from contactor to vacuum? If no, re-pipe per instructions. – Condensation is a normal occurrence, insulate vacuum manifold. ▪ 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.
	<ul style="list-style-type: none"> ▪ Liquid temperature below design specification. 	<ul style="list-style-type: none"> ▪ Raise temperature.
	<ul style="list-style-type: none"> ▪ Liquid flow rate higher than design specification. 	<ul style="list-style-type: none"> ▪ Reduce flow rate.
	<ul style="list-style-type: none"> ▪ Low sweep gas flow rate. 	<ul style="list-style-type: none"> ▪ Increase sweep gas flow rate.
	<ul style="list-style-type: none"> ▪ Unequal liquid flow through contactor trains. 	<ul style="list-style-type: none"> ▪ Verify train flow rate. ▪ Adjust valves accordingly to equalize flow rates.
High liquid-side pressure drop.	<ul style="list-style-type: none"> ▪ Dust covers used in shipping may not have been removed. 	<ul style="list-style-type: none"> ▪ Verify dust covers /end cap plugs have been removed.
	<ul style="list-style-type: none"> ▪ Particulate accumulation on shell side. 	<ul style="list-style-type: none"> ▪ Check filter system. ▪ Clean contactors. Refer to Cleaning Guidelines. ▪ Dissolve particles if soluble in acid or base. ▪ Replace contactors. ▪ Check flow rate: (do not exceed max.) <ul style="list-style-type: none"> – See table 5 in this guide for max flow rates.

XIX. Troubleshooting (Continued)

Problem Description	Probable Cause	Corrective Action
Significant liquid passage into gas stream.	<ul style="list-style-type: none"> ▪ Verify the liquid inlet is connected to the shell side port. 	<ul style="list-style-type: none"> ▪ Change piping connections.
	<ul style="list-style-type: none"> ▪ Center seal o-rings may not be sealing. 	<ul style="list-style-type: none"> ▪ See Contactor Assembly and Disassembly Instructions for details on how to fix this problem or contact a 3M representative.
	<ul style="list-style-type: none"> ▪ Contactor shell side o-rings may not be sealing. 	<ul style="list-style-type: none"> ▪ Remove and install new o-ring if appropriate. See contactor Assembly and Disassembly Instructions for details.
	<ul style="list-style-type: none"> ▪ Verify contactor integrity. 	<ul style="list-style-type: none"> ▪ Pressurize shell side with water to 4.2 kg/cm² (60 psi, 4.1 bar). ▪ Monitor for water dripping from open lumen port(s).
	<ul style="list-style-type: none"> ▪ Membrane break through (wet-out). If surfactants, oils, and/or alcohols have been introduced to the membrane, wet-out may have occurred. 	<ul style="list-style-type: none"> ▪ Rinse and clean the contactor. ▪ Remove fluid and dry the membrane thoroughly. See Cleaning Guidelines for drying procedures.
Nuts are seizing when I tighten them.	<ul style="list-style-type: none"> ▪ The nuts should not be quick driven onto the bolts. 	<ul style="list-style-type: none"> ▪ Nuts should be driven slowly by hand to prevent galling.
	<ul style="list-style-type: none"> ▪ Using power driven tools can produce excessive friction and increase the risk of galling. 	

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