Boiler Feed Water Degasification Using Membrane Contactors—
New Methods for Optimized Performance

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Abstract -

Membrane Contactors have been used to remove dissolved oxygen in boiler feed water systems for years. This report reviews various system designs and discusses how Membrane Contactors can be optimized in boiler feed water applications for removal of dissolved oxygen as well as carbon dioxide. The report also highlights what advantages membrane systems have over conventional oxygen and carbon dioxide removal technologies. New methods of degassing that improve the overall performance of Membrane Contactors in boiler feed water systems will also be introduced.

Membrane Contactors -

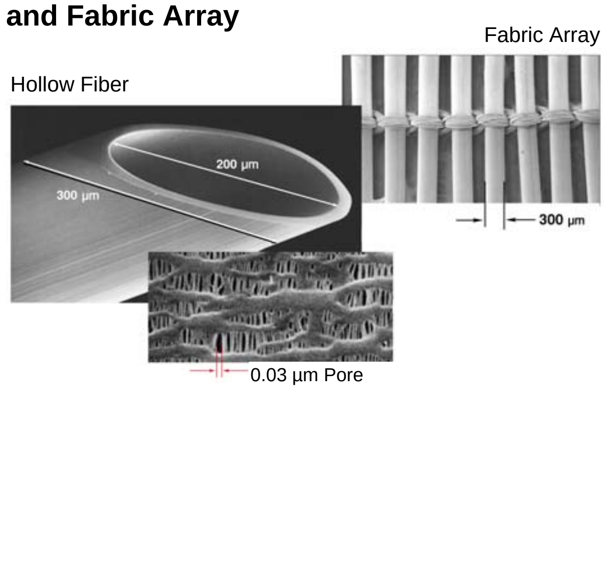
Membrane Contactors are devices that provide very efficient mass transfer between gases and liquids. These devices utilize microporous, hydrophobic hollow fiber membranes that contain a large surface area, which promotes ideal mass transfer. By controlling process conditions within the contactor, systems can be designed to remove gasses from or dissolve gases into water. These devices have been commercially available for industrial use for over fifteen years.

First developed as a means to remove dissolved gases from small flow applications, the technology has rapidly evolved and is suitable for very large-flow water systems in the power, pharmaceutical, food and beverage and microelectronics markets. Membrane Contactors are currently processing systems with flow rates as high as 1,696 m3/hr (7,462 gpm) and as small as a few ml/min.

In a typical design, water flows on one side of the microporous hollow fiber membrane. Gas flows on the other side of the membrane. Since the membrane is hydrophobic and the pores are very small, liquid will not pass through the pores. Pores in the membrane fiber provide a very stable gas/liquid interface. Manipulation of partial pressures at the interface allows gases to be added to or removed from the bulk water flow.

Manufacturing practices can vary as to how the fibers are packaged and assembled into a complete contactor device. One way is to knit the fibers into a fiber array sheet (see Figure 1) and roll the sheet around a perforated "distribution tube".

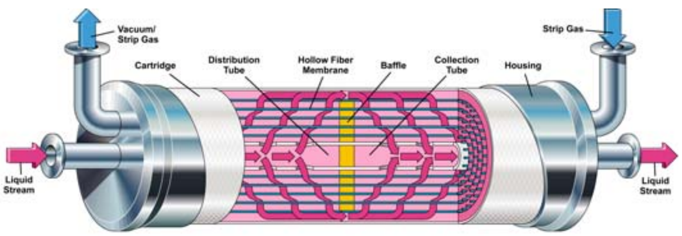
Figure 1: SEM's of Hollow Fiber Membrane and Fabric Array



With the fiber array wrapped around the distribution tube, the fiber ends can be potted and then cut to length to complete a finished cartridge. This cartridge design creates a bundle of hollow fibers. These fibers are arranged parallel to the distribution tube.

The cartridge can then be inserted into a housing and sealed. In a typical design of this nature, the completed assembly is analogous to a shell and tube heat exchanger as shown in Figure 2. The primary process water flow will flow on the outside, or shell side of the microporous hollow fiber membrane, while the gases flow on the inside of the fiber. The inside of the fiber is often referred to as “the tube side” or “lumen-side”.

Figure 2: The Inside of a Membrane Contactor



In the Membrane Contactor design shown in Figure 2, water enters the assembly via the distribution tube. At the distribution tube midpoint is a liquid-side baffle that forces the water to flow through perforations in the distribution tube and across the fibers in a flow path that is 90 degrees from its original flow direction. The water then takes a tortuous path across the fibers until reaching an annular space between the fiber cartridge and the housing wall. Traveling along this annular space the water will reach the baffle and make a 180-degree turn around the baffle, continue back across the fibers and enter the collection tube, and then exit the membrane contactor assembly.

Depending on process needs, water exiting the membrane contactor can then enter another contactor for degassing to a lower level or flow to downstream equipment for process use or further conditioning.

Boilers

Membrane Contactors have been successfully installed in hundreds of applications worldwide and in a variety of industries such as microelectronics, power generation, pharmaceutical, beverage, and others. In the majority of these applications the Membrane Contactors have been used to remove dissolved oxygen and/or carbon dioxide for high purity water within the process facility.

Purified water produced within a plant can be used for a wide range of applications. Use of the water in a boiler is one such application.

In a typical boiler application, water is supplied to a steel vessel in which a heat source is applied. The water is heated to its boiling point producing steam. The steam is then exported to downstream equipment. In many boiler applications the heated vessel will be fabricated from carbon steel or similar metallurgy. It is important to minimize and control the dissolved oxygen content in water that contacts these vessel components. This is due to the fact that dissolved oxygen in water will react with metals in the boiler system and cause corrosion.

In order to prevent corrosion, dissolved oxygen is typically removed and/or controlled by mechanical means or treated with chemicals. While chemical addition is a very effective method of reducing dissolved oxygen, there can be a significant cost associated with it. Chemicals have an associated cost of procurement as well as costs required for equipment and personnel to monitor and maintain proper chemical levels. Storing and handling chemicals on-site also brings environmental and safety hazards that are prompting many facilities to reduce or eliminate chemical addition.

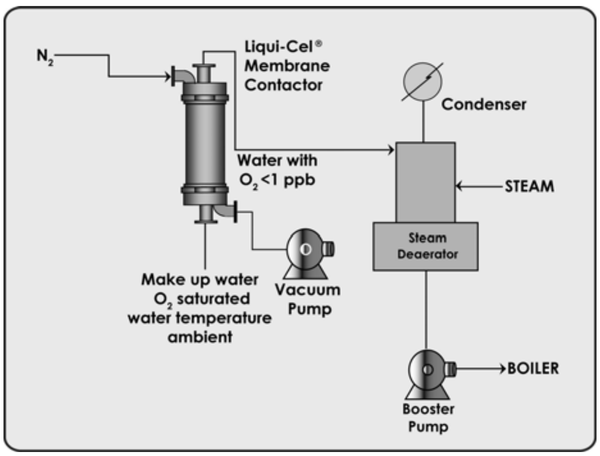
Chemical additives also increase the total dissolved solids (TDS) in the boiler water. Boiler operators must monitor TDS levels and maintain them within certain concentration limits. If TDS levels exceed proper operating limits, scale on the boiler tubes and other surfaces can occur. Fouling of the heat transfer surface in this manner will affect boiler efficiency and increase operating costs of the boiler. As chemicals are added to the boiler water, TDS levels will continue to increase. Once TDS levels reach a pre-determined limit, the boiler must be “blown-down”. This is essentially releasing a quantity of high TDS-water and replacing it with fresh make-up water until TDS levels return to proper levels.

While blow-down is an effective means of controlling TDS levels, blow-down releases hot water. Fresh water replaces “blown-down water” and the fresh water must be heated back up again. Additional chemicals may also need to be added. Blow down creates a heat loss and reduces efficiency to the boiler; it is costly and is time intensive.

Membrane Contactors

In Figure 3 a simple flow diagram of a typical boiler system is shown. In this drawing a membrane contactor system is shown on the make-up side of the process.

Figure 3: Basic Boiler System with Hybrid Liqui-Cel Contactor System and Steam Deaerator



Membrane Contactors can be used to remove the dissolved oxygen from boiler water. With the proper configuration and system design Membrane Contactors can remove essentially all of the dissolved oxygen present in the water stream. Membrane Contactors can be used as stand alone Deoxygenation systems or they can be used with existing technology as a hybrid system.

Traditional deaerators may only remove dissolved gasses to 7-10 ppb. This small amount of oxygen is still corrosive to the system. Installing a membrane system in conjunction with the traditional vacuum deaerator will allow the lowest possible levels of dissolved gasses to the boiler. Furthermore, the condenser will introduce additional oxygen to the system; the membrane contactors will remove this prior to the boiler as well.

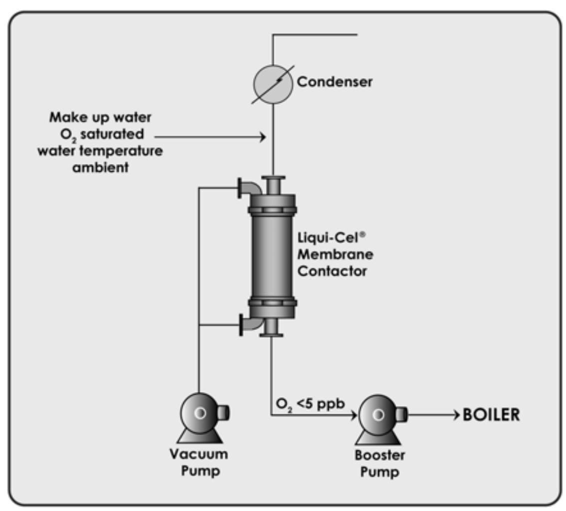
One operating design for Membrane Contactors is the sweep assisted vacuum scenario. In this flow scheme a small amount of an inert gas such as nitrogen is used in combination with a vacuum source. See Figure 3. While this design is very simple to build and operate, one obvious limitation can be the availability of a sweep gas. An inert gas generator can be provided if shown to be cost effective. A properly designed membrane contactor system of this nature can eliminate oxygen-scavenging chemicals as well as operate unattended.

In the absence of a low cost sweep gas, a vacuum pump in combination with a chemical system can also produce very low dissolved oxygen levels in the effluent. This method reduces chemical usage but does not eliminate it completely. Economics of each design will depend on each specific application.

New Operating Efficiencies Demonstrated with Membrane Contactors

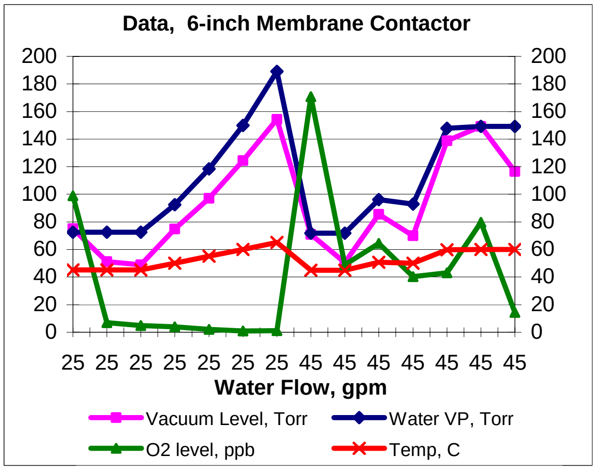
Recently work has been completed in which a Membrane Contactor has been used to treat water at elevated temperatures. This work has shown that dissolved oxygen levels of less than 5.0 ppb can easily be reached. Most importantly this performance is achieved without the use of a sweep gas or additional chemicals.

Figure 4: Vacuum-only Membrane Contactor System Producing Effluent Water with < 5ppb of Dissolved Oxygen



In Figure 5 the basic system in which this work was conducted is illustrated. In this work, tests were conducted over a range of flow rates, vacuum levels and inlet feed temperatures. A detailed plot of some of the data is provided in Figure 5.

Figure 5: Data of One 6-inch Contactor Operating in Vacuum Mode



A review of the data shown in the graph indicates several very important points regarding the use of a membrane contactor for this application. An initial key point is that dissolved oxygen levels can be reduced to well below 10.0 ppb with a single contactor. In more "traditional" membrane contactor designs several contactors in series are typically required to reach these lower levels of dissolved oxygen.

The data shown in the plot help explain why this is the case. It should be first noted that at elevated temperatures like the ones used in this study, the inlet dissolved oxygen levels are reduced. This is due simply to the fact that with increasing water temperature, the amounts of gases that can be dissolved in water are reduced significantly. As a result the oxygen load supplied to the membrane contactor is reduced. In the cases shown here, the feed temperature ranged from 45 – 60 °C. In this temperature range, the inlet dissolved oxygen level will vary from 5.0 – 6.0 ppm as compared to 8 – 10 ppm for ambient temperatures of approximately 20 °C.

Another key point that comes from this study is that it becomes obvious that overall system performance is very dependent on the vacuum pressure. An interesting aspect of this fact is that when the vapor pressure is plotted on the same chart it becomes clear as to the optimum operating pressure for the vacuum system. It can be seen from the chart that even with increasing vacuum pressure, very low dissolved oxygen levels are obtainable. It is important to note that as the vacuum pressure equals or exceeds the vapor pressure of the water inside the contactor, system performance drops dramatically. Therefore designing a membrane contactor system becomes a very straightforward process.

The study at elevated temperatures provides several key lessons and conclusions that can be used to apply Membrane Contactors in boiler systems. The study was conducted with a membrane contactor with nominal dimensions of 6-inches diameter and 28-inches in length. The housing used was ABS plastic. The robustness of a membrane device with plastic components was demonstrated in this application.

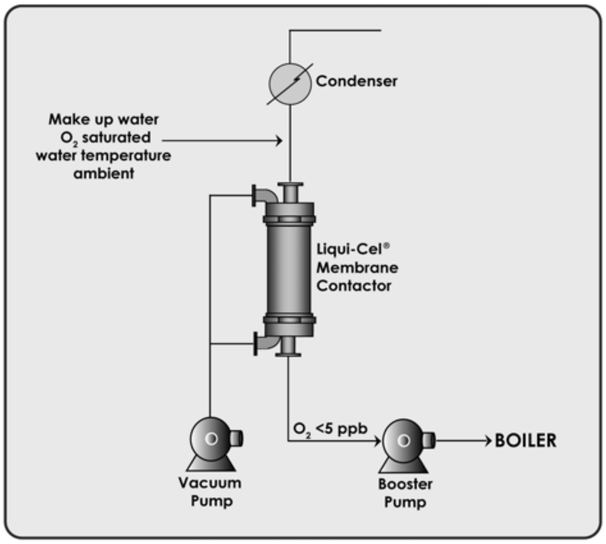
Another observation from this study showed that at elevated temperatures, the amount of water vapor passing through the membrane is significantly higher than at lower temperatures. This was seen to be a major component of this vacuum only configuration. Calculations and observations indicate that this water vapor acts as a sweep gas, therefore eliminating the need for additional gas.

The success of this study also opens a whole new area for application of the Membrane Contactors in boiler systems. Previous applications have involved placing the membrane unit only on the make-up side of the system. It can now be seen that installing the Membrane Contactor System in place of the steam deareator is possible. (see Figure 6).

There are several advantages of this configuration:

- Space – A membrane system is inherently modular and is easily adaptable to a given footprint.
- Operational ease – A system of this type is easily controlled. No special controls are required.
- Low energy consumption – The vacuum pump requires a small horsepower pump. Condensed water vapor from the system can be returned and recycled.
- Economics – It can also be shown that a membrane system will be economical as compared to a steam deaerator.

Figure 6: Using a Membrane Contactor system in place of a traditional vacuum/ steam deaerator



The table in figure 7 provides a comparison of Membrane Contactors and traditional deaerators in terms of size and weight. Four different capacity boilers are listed. Membrane Contactor systems are much smaller and lighter weight in all cases. Additionally they are easy to expand as system requirements change.

Summary

Membrane Contactors have been installed in a wide variety of applications for over 15 years and have been proven as an effective means of removing gases from liquid streams. Membrane contactor technology continues to evolve to allow increased throughput and wider operating ranges.

Removal of dissolved gases in boiler loops is an application where Membrane Contactors can effectively compete and they offer key advantages for eliminating or reducing chemicals.

New advances in boiler degassing applications using elevated temperatures and vacuum only mode with Membrane Contactors provides a new level of flexibility to the boiler engineers in protecting the boiler from corrosion. Membrane Contactors can also offer savings in space, energy and operating expenses.

Figure 7: Comparison of Dimensions and Weights Between Conventional Deaerators and Liqui-Cel Membrane Contactor Systems

SYSTEM SPECIFICATIONS	Traditional Deaerator	Liqui-Cel 6 inch, 1x2 system	Traditional Deaerator	Liqui-Cel 6 inch, 1x2 system	Traditional Deaerator	Liqui-Cel 10 inch, 1x2 system	Traditional Deaerator	Liqui-Cel 10 inch, 1x2 system
Outlet Capacity								
lb./hour	9,000	9,000	18,000	18,000	30,000	30,000	50,000	50,000
Gpm	18	18	36	36	60	60	100	100
System Dimensions*								
H x D x W								
Feet	7x8x10	7x3x2	7x8x13	7x3x2	7x8x17	7x4x2	8x9x18	7x4x2
M	2.1x2.4x3	2.1x.91x.6	2.1x2.4x4.0	2.1x.91x.6	2.1x2.4x5.2	2.1x1.2x.6	2.4x2.7x5.5	2.1x1.2x.6
Shipping Weight								
Lb	1,920	625	2,360	625	3,010	880	4,200	880
Kg	871	283.5	1,070	283.5	1,365	399.1	1,905	399.1