NOVEL MEMBRANE TECHNOLOGY FOR DEGASSING BOILER FEED WATER

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INTRODUCTION

Pretreatment of boiler feed water is an important part of operating any boiler system, since dissolved gases, such as carbon dioxide and oxygen, react with metals in the boiler system, resulting in boiler corrosion. Several different technologies have been widely used to remove contaminants, which includes reverse osmosis membrane and ion exchange systems. Forced draft degasifiers, chemical agents and steam de-aerators have been used to remove dissolved gases. Membrane contactors offer unique advantages in degassing boiler feed water, which includes:

- No chemical consumption. Chemicals have been used to control dissolved oxygen content in a boiler. Addition of chemicals causes increase in blow down frequency, which increases operating cost not only due to chemical costs, but also due to cost of water replacement and additional steam needed to reheat water lost during blow down. In practice, 10 ppm of sodium sulfite is needed to remove 1 ppm of dissolved oxygen.
- Increased operating cost of the boiler. For a 10,000 lb/hr boiler, using natural gas and operating at a pressure of 50 psig and 80% efficiency, with inlet dissolved oxygen of 9 ppm, the yearly chemical, blow down water and additional energy costs is estimated to be about $14,000 compared to $5,600 for degassed water. This gives a net savings of $8,400 per year using a degassifier instead of chemicals.

PRINCIPLE OF DEGASSING

To understand the operation of the membrane system, it is first important to understand the laws governing degassing of gases from drinking water. Dalton’s Law states that the total pressure of a gas mixture is equal to the sum of the partial pressures of the individual gases in the gas mixture, i.e.,

$$P_{Total} = P_1 + P_2 + P_3 + \ldots\ldots\ldots \qquad (1)$$

The partial pressure of a specific gas can be written in terms of its concentration:

$$P_i = y_i P \qquad (2)$$

where y_i is the mole fraction of gas I in the gas mixture.

According to Henry's Law, the partial pressure depends on the concentration of gas in the liquid phase, i.e.,

$$P_i = H_i x_i \tag{3}$$

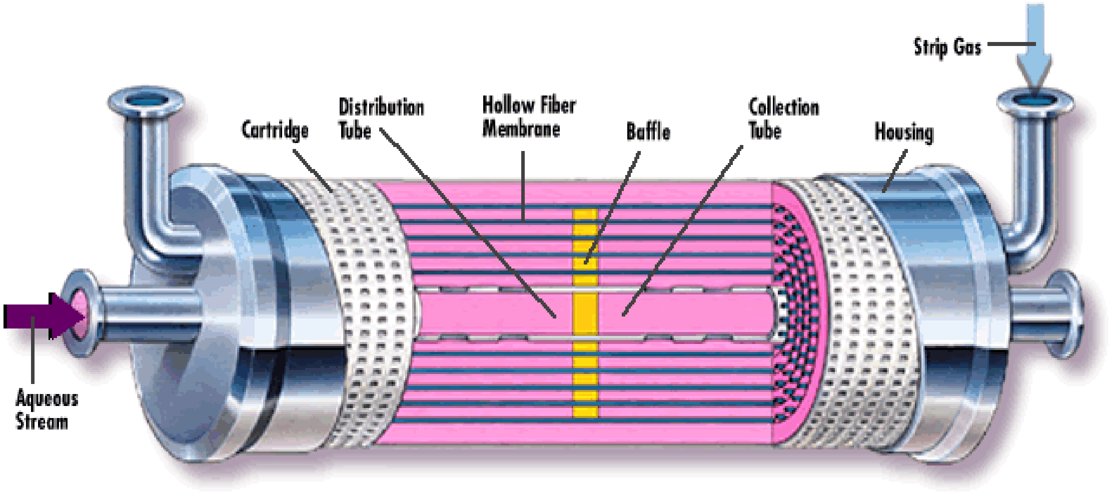
where P_i is the partial pressure of the gas, and x_i is the gas concentration in the liquid phase (dissolved gas). Hence the amount of gas that dissolves in water is proportional to its partial pressure.

To transfer the gas from its dissolved state to the gas phase, there must be a driving force. In the case of the membrane system, it is the partial pressure difference of the gas. From Henry's Law (equation 3) we know that if the partial pressure of the gas is reduced, its concentration in the liquid phase will also decrease, which means that dissolved gas will transfer to the gas phase. From equation (2), the partial pressure of the gas can be reduced by reducing the total pressure. Hence, one way to reduce the dissolved concentration of a gas is by simply reducing the total pressure. However, this requires a vacuum pump to reduce the total pressure, and vacuum pumps can be expensive. A second strategy is by reducing the concentration of the gas in the gas phase (y_i in equation (2)), which also reduces the partial pressure and hence its concentration in the dissolved state. This strategy does not require a vacuum pump, which is advantageous.

MEMBRANE SYSTEMS

What is a membrane system ? A membrane system can be two types: (1) hollow fiber contactor; and (2) spiral wound module. A hollow fiber system consists of hundreds of porous hollow fibers (each fiber has an outer diameter of 300 microns and an inner diameter of 200 microns) that are glued to a plate which allows the fluid flowing inside the fibers to be isolated from the fluid flowing outside the fibers. Water containing the dissolved gas, such as hydrogen sulfide flows outside the fibers, which is called the "shell side". Ambient air, not containing any hydrogen sulfide flows inside the fibers at ambient pressure or at reduced pressure (partial vacuum conditions) and this is the strip gas. Figure 1 shows a schematic of the hollow fiber membrane module.

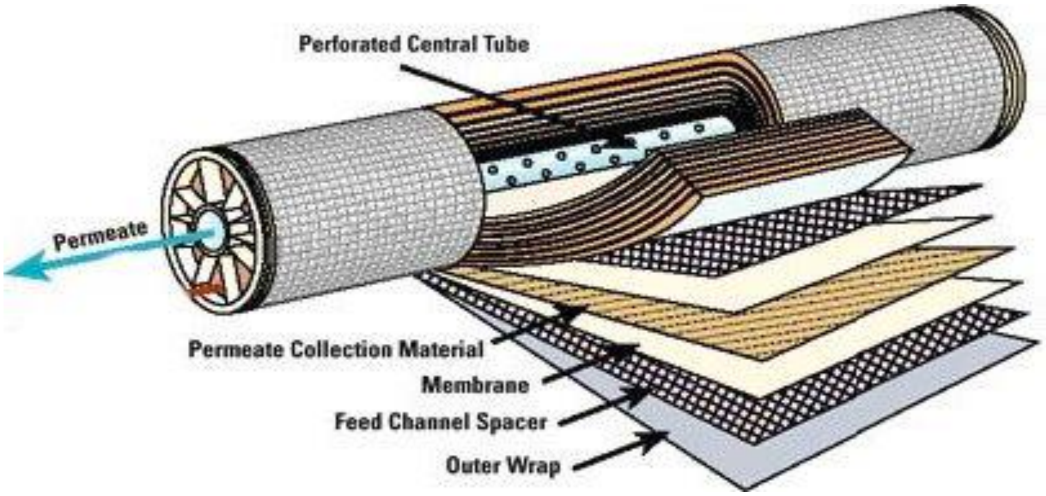
Figure 1. Schematic of the Hollow Fiber Membrane Module.



Dissolved hydrogen sulfide gas transfers from the aqueous phase, flowing outside the fibers, to the air phase, flowing inside the fibers, since the concentration and perhaps the total pressure in the gas phase is less than the concentration in the aqueous phase. If both reduced total pressure and ambient air with zero hydrogen sulfide concentration is used as the strip gas, the degassing of hydrogen sulfide will be faster and more efficient. This membrane module can be mounted horizontally or vertically and can be located at ground level after the liquid pump.

Another type of membrane system is the spiral wound module, which uses a flat membrane sheet rather than porous hollow fibers. The flat membrane sheet is wrapped with a spacer around a tube with holes in it. The water containing dissolved gases flows on one side of the membrane sheet while air containing no hydrogen sulfide and at reduced pressure flows on the other side and is collected from the inner tube as permeate. Figure 2 below shows a spiral wound membrane module.

Figure 2. Spiral Wound Membrane Module.



There are different costs of a membrane module for a hollow fiber system and a spiral wound module. Generally, the hollow fiber module is more expensive than a spiral wound module. In this application, a pleated membrane spiral wound membrane module, shown in Figure 3, will be used since it offers the advantages of a flat membrane spiral wound design as well as high surface area in a compact geometry due to the pleated shape of the membrane material. In addition, the membrane material selected for this application is Teflon® which is chemically inert, with minimal extractables, for drinking water applications. The main advantages of Teflon® material are:

- Extremely low extractables, which is important for drinking water applications;
- Precise pore size;
- Natural barrier to water without the use of surface modifying agents, which can leach or wash out;
- Reliable integrity under severe process conditions; and
- Meets FDA requirements for food contact use and passes USP Class VI biological tests for plastics.

Figure 3. Figure of a single 40" length pleated membrane cartridge with double O-ring seal at the top for connecting to holder within the Degassing vessel.

DESIGN OF THE MEMBRANE DEGASSING SYSTEM

The basic degassing unit is designed using multiple cartridges of the same design to enable the membrane cartridges to be changed or replaced, when needed. The design of a single membrane cartridge is summarized below in Table 1.

Table 1. Membrane Cartridge Specifications

Specification	Value
Membrane Material	Teflon®
Outer Guard	Polypropylene
Sealing method	Thermal bonding (no adhesives)
Gaskets and O-Rings	Teflon®
Absolute pore size	0.1 µm
Maximum operating temperature and pressure	150°F (37°C) at 80 psi differential (5.6 kg/cm^2) 150°F (65°C) at 60 psid (4.2 kg/cm^2) 180°F (82°C) at 30 psid (2.1 kg/cm^2)
Diameter	2.75 inches (7 cm)
Nominal Length	40 inches (100 cm)
Maximum water flow rate	2,500 gpm
Dissolved gas removal efficiency	> 95% of inlet dissolved gas concentration

The cartridges are installed in a 316 stainless steel vessel, as shown in Figure 4. The vessel which is 36” (length) x 18” (width) x 48” (height) contains four rows of two cartridges, with baffles between each row to allow water to contact each set of cartridges with minimal by-passing. In addition, the vessel is filled with a proprietary 316 stainless steel packing material (not shown in the drawing), which surrounds each cartridge. This packing material creates turbulence and forces good contact between the cartridge element and the water, which further minimizes fluid by-passing and ensures good mixing. This turbulent mixing is critical for effective degassing of the water. Each cartridge is mounted in a holder, which accommodates the two O-rings at the top of each cartridge, which ensures no leaks and the cartridge can be easily removed by twisting it. This makes it very easy to replace cartridges in the field, when needed. Each cartridge holder is connected to a manifold, which is connected to a vacuum pump, as shown in Figure 5. Dissolves gases including hydrogen sulfide are removed through the membrane pores into the vacuum manifold, where they are then separated from water and discharged into the atmosphere. If hydrogen sulfide emission results in odor or corrosion issues, a carbon canister can be mounted at the exit of the vacuum pump to adsorb the hydrogen sulfide gas.

The vacuum pump (shown in Figure 5) discharges water and gases into a separator tank, where the gas and liquid are separated by centrifugal action and the force of gravity, with vapor exiting the top and liquid discharging at the bottom of the separator tank. In a recirculated seal fluid arrangement, seal liquid is recycled back to the pump, as shown in the figure. Initially, water is added to the vacuum pump to form the liquid seal. There is an overflow from the liquid separator tank to remove excess fluid.

A single vacuum pump can handle multiple degassing units, which can be connected in series and/or parallel to handle larger flow rates and achieve higher degassing efficiency of other gases, such as carbon dioxide, oxygen, nitrogen, etc. Each degassing unit is installed on a 4 ft x 4 ft concrete pad, which accommodates the vessel and a skid-mounted vacuum pump, separator vessel and control box.

Figure 4. Degassing Unit Vessel Drawing for 2,500 gpm water flow rate.

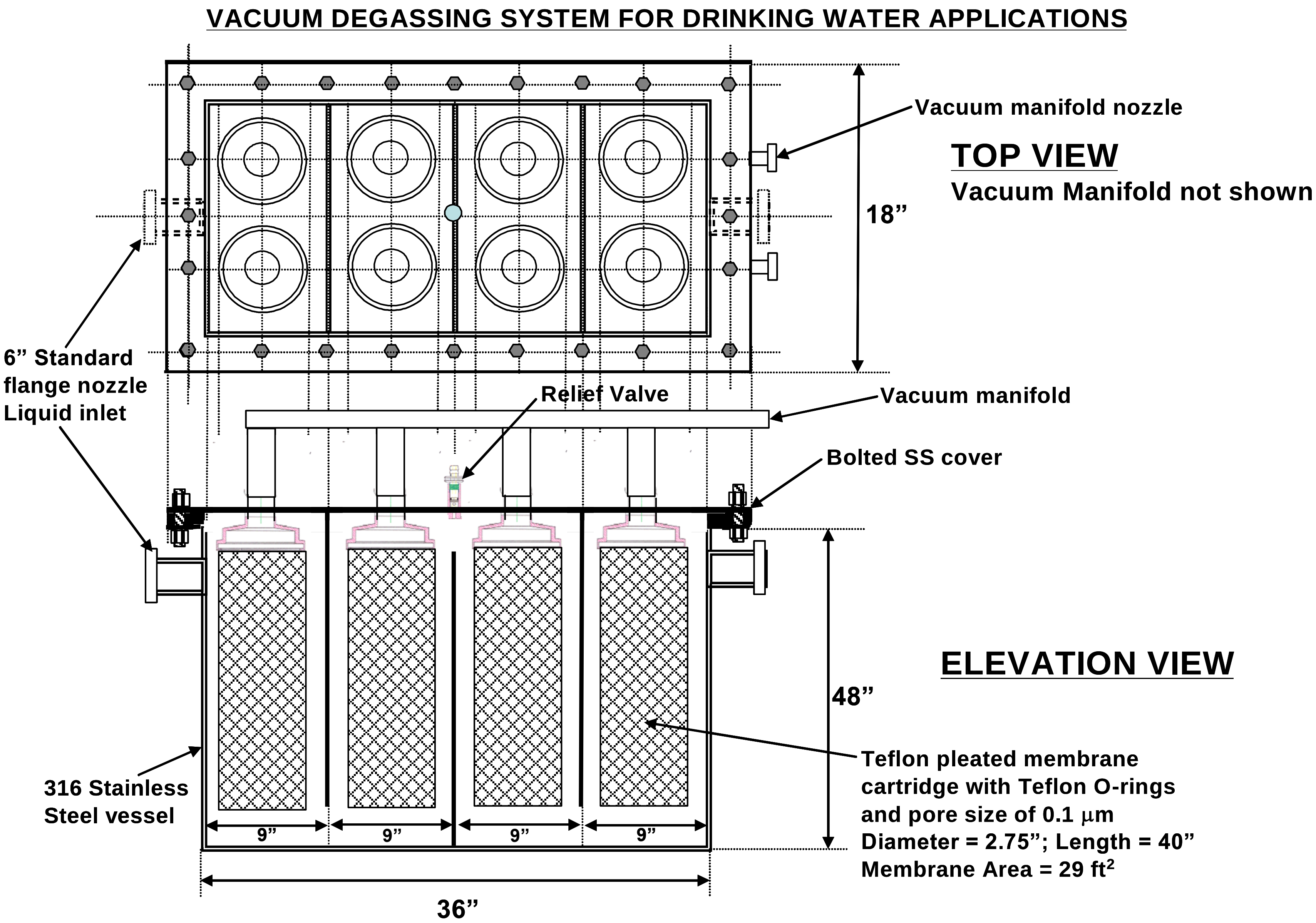
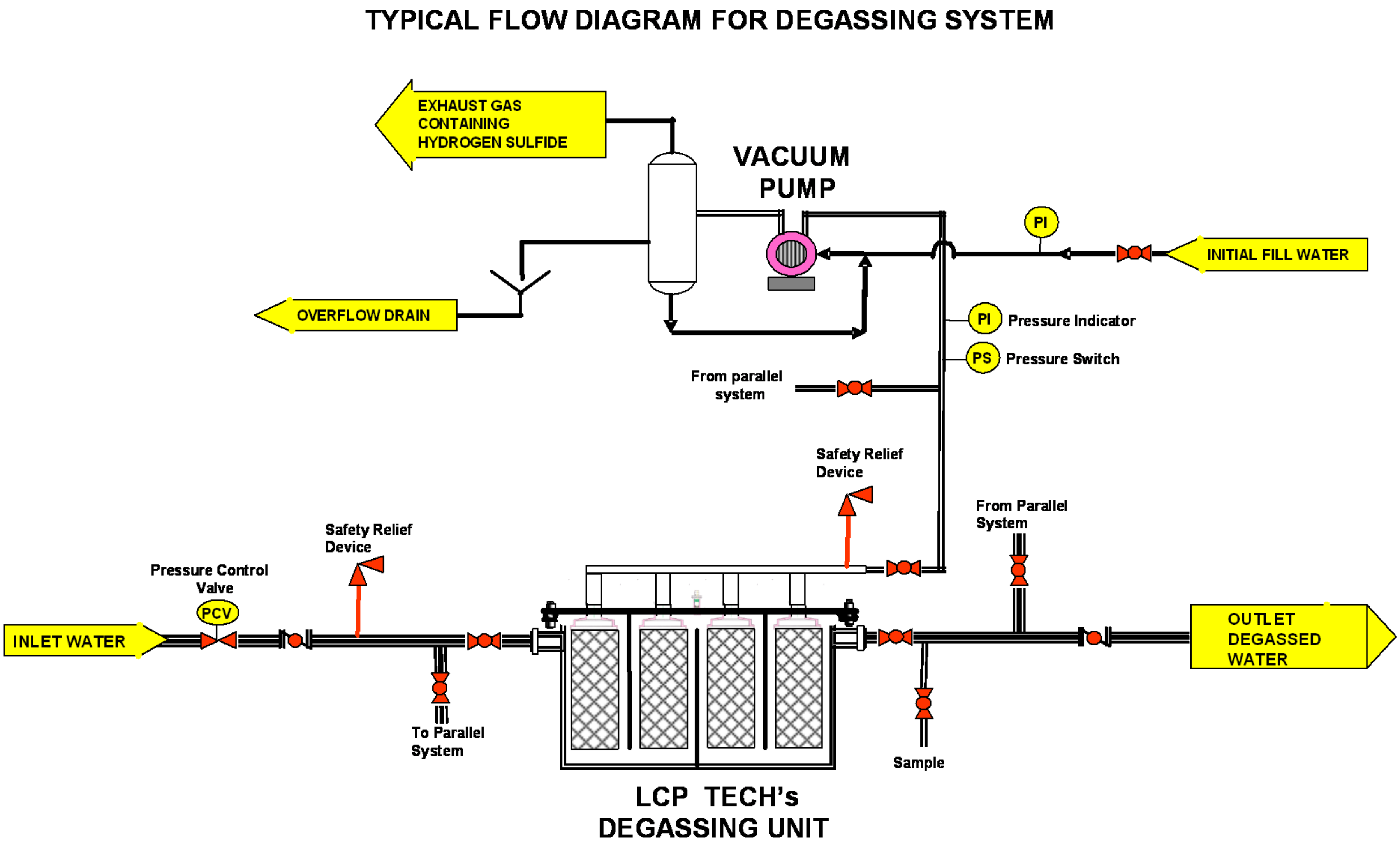


Figure 5. Process Flow Diagram for the Degassing Unit.



The advantages of a membrane system when compared to the traditional plate system are as follows:

- High removal efficiency of all dissolved gases – hydrogen sulfide, carbon dioxide, oxygen and nitrogen; Removal efficiencies in excess of 90% are easily obtained as compared to 30% for a plate system;
- Is installed after the feed pump at ground level, as compared to a plate system that has to be installed at the top of the tank;
- The hydrogen sulfide gas is removed through a pipe and hence can be treated using a activated carbon or biofiltration system, thereby preventing corrosion of surrounding structures and emissions of odors;
- Since vacuum is used to extract the hydrogen sulfide, there is no air that can cause oxidation of the ferrous iron to ferric, which completely avoids precipitation and scaling; this prevents the use of acid for pH adjustment, scaling of the membrane module, etc.
- Since ambient air is not used to extract the hydrogen sulfide, no air contaminants, such as smog, dust, bacteria, etc. can get into drinking water; and
- The pleated membrane system for handling 2,500 gpm of water flow has dimensions of 48” (height) x 36” x 18” 316 Stainless steel vessel, with a FRP skid that is placed next to the vessel, and the entire degassing system can be installed on a 4 ft x 4 ft concrete pad.