DuPont™ Ligasep™
Degasification Modules
Technology Summary
How Gases Get into Water

Air is made up mostly of nitrogen (N₂) and oxygen (O₂) – at atmospheric pressure, 79% N₂ and 21% O₂. Whenever air is in contact with water, these gases naturally dissolve into the water. A glass of water will contain around 8.5 ppm of oxygen and 14 ppm of nitrogen because it is in contact with the atmospheric air. Carbon dioxide (CO₂) will dissolve in water as the water flows over the earth. Water will dissolve common minerals such as calcium carbonate and magnesium carbonate.

When the minerals dissolve they form calcium and magnesium ions as well as carbon dioxide and carbonic acid (H₂CO₃—the ionizable species in equilibrium with gaseous carbon dioxide when CO₂ is dissolved in water):

\[
\text{CaCO}_3 + 2\text{H}^+ \rightarrow \text{Ca}^{2+} + \text{CO}_2 + \text{H}_2\text{O}
\]

\[
\text{CO}_2(g) + \text{H}_2\text{O} \leftrightarrow \text{CO}_2(aq) + \text{H}_2\text{O}
\]

\[
\text{CO}_2(aq) + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3
\]

The amount of carbon dioxide dissolved into the water will depend on how much calcium carbonate and magnesium carbonate the water source has contacted; some regions have much higher amounts of these minerals than others. Water with large amounts of minerals is commonly referred to as hard water.

Why Gases are Removed

Oxygen

Oxygen is removed from water because it reacts with metals and will oxidize any metal it contacts. Two major industries concerned with oxygen reacting with metals are the Power Generation industry and the Semiconductor Manufacturing industry.

Steam power plants generate steam to create a force to push a series of blades mounted on a shaft (similar to a propeller). As the shaft rotates it converts the mechanical energy to electrical energy. These blades are made of metal and are prone to oxidation. If the metals in the turbine blades start oxidizing they will become damaged and impact the performance of the turbine.

Semiconductor manufacturing plants use a large volume of water to rinse the silicon wafer as they go through different processing steps. The wafer may go through 40 – 50 individual processing steps and each step will be followed by a rinse to remove chemicals used in the process. Oxygen in the water will react and oxidize metals used in the integrated circuit. The oxides will impact the circuits and create defects.

Target dissolved oxygen:
- < 1 ppb (part per billion) for integrated circuits
- < 50 ppb for TFT displays
- < 10 ppb for power plants

Carbon Dioxide

Water purity is often measured by its ability to conduct electricity. Ions in the water will allow the water to conduct electricity. Ultrapure water will have a very low conductivity indicating it has very few or virtually no ions in the water. Carbon dioxide will exist in equilibrium with carbonic acid, which will ionize and increase the conductivity of water.

Ion exchange resin will remove ions and can be used to remove carbon dioxide. As the level of carbon dioxide increases it becomes more economical to remove the carbon dioxide using a mechanical method rather than ion exchange. It is common to install a decarbonator (aka, degaser) to remove dissolved carbon dioxide from water.

- Target CO₂ < 3 ppm
How to Remove Gases from Water

In order to understand the mechanics behind gas removal it is important to review two chemical engineering principles. These principles are simplified below.

**Henry's Law**
Gases will dissolve in water whenever they are in contact with the water. The amount of gas that will dissolve in water is proportional to the pressure of the gas. This is governed by a chemical engineering principal called Henry’s Law.

**Henry’s Law:** \( P = Hx \)
- \( P \) = gas partial pressure
- \( H \) = constant
- \( x \) = amount of gas dissolved into the water

**Dalton’s Law of Partial Pressure**
In a gas mixture each gas exerts its own pressure or partial pressure. The total gas pressure is the sum of all of the partial pressures in the gas mixture. The partial pressure of a gas is the total pressure times the % fraction of the gas in the gas mixture.

**Dalton’s Law:** \( Pt = P_1 + P_2 + P_3 + \ldots \)
- \( Pt \) = total pressure of the gas mixture
- \( P_1 \) = partial pressure of gas component 1
- \( P_2 \) = partial pressure of gas component 2

**Example:**
Air is made up of 21% oxygen and 79% nitrogen. At one atmosphere oxygen exerts a partial pressure of 0.21 atmospheres and nitrogen 0.79 atmospheres. Oxygen and nitrogen will dissolve in water proportional to these partial pressures.

If we replace the air in contact with the water with nitrogen, the partial pressure of the nitrogen will increase to 1.0 atmospheres and the oxygen partial pressure will decrease to 0 atmospheres. Additional nitrogen will dissolve into the water and oxygen will subsequently move out of the water.

Gas removal techniques will use this concept to lower the partial pressure of the gas in contact with the water to remove the gas from the water.

Conventional degasification technology sprays the water into droplets in a tower; creating droplets increases the gas liquid contact area and improves the efficiency. The tower is designed to operate under a vacuum (to lower the total pressure of the gas mixture) or with a sweep gas (to replace the gas in contact with water with another gas). When removing carbon dioxide, air is often used to maintain a CO\(_2\) free gas in contact with the water. In the case of carbon dioxide, the gas solubility is very high so the air must be continuously replaced to assure that no carbon dioxide is in the gas that is in contact with the water.

Membrane degasification technology brings the gas and liquid phases in contact with each other across a hydrophobic membrane. The membrane does not allow water to pass through the membrane but freely allows gas to pass through. This creates a large contact area (10X that of a tower) that maximizes the efficiency. Just as in a tower, the gas concentrations and pressure on one side of the membrane are adjusted to remove gases from the water.
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