Hydrogen Permeation – Hydrogen Applications

Introduction

Hydrogen (H) is the simplest and smallest atom element in nature. Water, acids, bases, and the entire family of organic compounds all contain hydrogen. While hydrogen is not considered corrosive, it can cause problems with pressure transmitters if the application is not properly evaluated.

Hydrogen is normally found in a diatomic state as a molecule composed of two hydrogen atoms (H₂). In this state, molecules will not penetrate the thin metal barrier diaphragms. However, if the hydrogen splits into two hydrogen ions (H⁺ atoms), it can penetrate barrier diaphragms because H⁺ ions are smaller than the space between molecules of the barrier diaphragm metal.

Changes can occur at high temperature or high pressure in hydrogen-rich processes. In a pure hydrogen environment, hydrogen molecules collide with each other and bonds are broken. In applications where hydrogen is part of large molecules, hydrogen ions can randomly become dissociated from molecules in many ways.

After separating from the molecule, the H⁺ ions can pass through the barrier diaphragms and re-combine into H₂ molecules, which become trapped. Gradually the H₂ molecules dissolve into the transmitter’s fill fluid and over time the fill fluid becomes saturated. The concentration of trapped H₂ depends on the operating pressure (static pressure) of the system and the temperature. The moment the static pressure is relieved, the trapped H₂ gas expands and a bubble appears.

Hydrogen gas trapped inside a transmitter causes zero and span shifts over time as the trapped gas increases degrading performance of the transmitter. As the hydrogen gas builds up, it causes outward expansion (‘bulging’) of the barrier diaphragms leading to cracks and transmitter failure through the loss of fill fluid.
A typical pressure transmitter diaphragm measures 0.002 inches (0.025 to 0.050 mm) thick. If the permeation continues long enough, permanent distortion of the diaphragm will take place as the diaphragm continues to expand.

This distortion is most evident and damaging once the static or operating pressure is relieved from the transmitter with the trapped (H₂) still at the static pressure behind the diaphragm. The trapped hydrogen gas occupies a greater volume than the liquid fill fluid and ‘bulges’ or ‘blows-out’ the diaphragm.

**Applications**

Where to watch for H₂ permeation? Pure hydrogen applications are the obvious source of hydrogen permeation. However, H₂ permeation can occur in applications where hydrogen is not the main component. Examples of this are as follows:

- Hydro forming or alkylation processes using hydrofluoric acid (HF) can lead to the same problems when hydrogen ions are liberated
- Steam at high temperatures can cause corrosion of metal diaphragms, and hydrogen ions can be generated

**Diaphragm Materials**

Diaphragm metal material affects the rate of hydrogen permeation because molecular lattice spacing is different in each metal. The nickel (Ni) content of the metal also affects the rate of hydrogen permeation. While not totally understood, the rate of hydrogen permeation increases exponentially with the Nickel content.

Stainless steel has the lowest nickel content and is the diaphragm material of choice for most applications. Nickel-based metals, like Hastelloy C-276 and Monel, should be avoided as well as Tantalum. However, in hydrofluoric acid (HF) service, Monel is the suggested diaphragm material; as a result, alternate preventive measures must be taken.

**Solutions and Prevention**

Although expensive, gold-plating the barrier diaphragms offers the best protection. A thin layer (0.00012 inch (3 μm) thick) of 99.9% pure gold virtually eliminates hydrogen permeation without itself being affected by the process. However, the gold plating should not be used to enhance resistance to corrosion. The gold plating is too thin and too porous to provide an effective barrier to corrosion.

**Projected Life of Transmitters**

The expected operating life of a transmitter is typically extended 5 to 10 times by gold plating. In situations where pure hydrogen is found at 200 °C and 150 barG pressure, a Hastelloy C-276 diaphragm failed after 6 months in service. By contrast, the transmitter life was 4 years with gold-plated diaphragms. Stainless steel diaphragms in this service last 3 to 5 times longer.
With varying temperature, the operating life of a transmitter increases by about 33 to 40 times per 100 °C temperature reduction. Thus the process temperature at the diaphragm surface is a dominant factor in the mobility of the hydrogen ions, and any measure taken to reduce the temperature will significantly extend the operating life of a transmitter in hydrogen service. By comparison, reducing the static pressure from 150 barG extends the operating life only by about 20% per barG.

The best prevention is afforded by the proper installation and the correct choice of metals in hydrogen applications. The preceding does not mean that the universal choice of diaphragm material should be stainless steel. Contaminants, such as hydrogen sulfide, are commonly associated with hydrogen processes. In particular, if the hydrogen sulfide is wet, this can lead to Stress Corrosion Cracking (SCC). As a guide for hydrogen applications with or without hydrocarbons and hydrogen sulfide at 100 °C and 150 to 200 barG, the following table provides rough estimates of transmitter life:

<table>
<thead>
<tr>
<th>Process Condition</th>
<th>Process Fluid</th>
<th>Life Expectancy of Transmitter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3 Years</td>
</tr>
<tr>
<td>Dry</td>
<td>H₂</td>
<td>316L SS</td>
</tr>
<tr>
<td>Dry</td>
<td>H₂ + Hydrocarbons</td>
<td>316L SS</td>
</tr>
<tr>
<td>Dry</td>
<td>H₂ + HS</td>
<td>316L SS + Gold</td>
</tr>
<tr>
<td>Dry</td>
<td>H₂ + Hydrocarbons + HS</td>
<td>316L SS + Gold</td>
</tr>
<tr>
<td>Dry</td>
<td>HS + Hydrocarbons</td>
<td>316L SS + Gold</td>
</tr>
<tr>
<td>Wet</td>
<td>H₂ + Hydrocarbons</td>
<td>316L SS</td>
</tr>
<tr>
<td>Wet</td>
<td>H₂ + HS</td>
<td>C - 276 + Gold</td>
</tr>
<tr>
<td>Wet</td>
<td>H₂ + Hydrocarbons + HS</td>
<td>C - 276 + Gold</td>
</tr>
<tr>
<td>Wet</td>
<td>HS + Hydrocarbons</td>
<td>C - 276 + Gold</td>
</tr>
</tbody>
</table>

These guidelines may be useful. However, Honeywell provides no assurances or guarantees as to their appropriateness in a specific application. It is customer experience that is paramount.

- **Select** a diaphragm material that is inert to the process media — even if it has to be gold plated.
- **Keep** the temperature of the diaphragm as low as possible. Both corrosion and hydrogen migration accelerate rapidly as temperature is increased.
- **Gold plate** the diaphragms whenever hydrogen ion migration is a threat.
More Information
For more information on Hydrogen Permeation, visit www.honeywellprocess.com, or contact your Honeywell account manager.

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