HandyTube
A STEEL PARTNERS COMPANY

WHITE PAPER

Why High-strength Tubing is Essential to Hydrogen Refueling Stations

How high-strength stainless steel tubing plays a critical role in hydrogen refueling stations by preventing structural damage and ensuring operational success.

As commercial and industrial vehicle manufacturers look for more sustainable fuel alternatives to fossil fuels, hydrogen FCEV - Fuel Cell Electric Vehicles are gaining popularity. Hydrogen-based fuels are beginning to experience their own renaissance, but hydrogen's chemical and physical properties challenge implementation in refueling stations, inhibiting further adoption.

If internal systems are improperly designed, hydrogen damage to refueling station components can cause leaks. If there is a leak or ignition source, a fire or explosion can result. To minimize hydrogen's harmful effects, it is crucial to design fuel-transfer plumbing systems of hydrogen refueling stations with high-strength stainless steel tubing. Because of tubing's critical role in these plumbing systems, it is important to understand the key aspects of specifying tubing for hydrogen refueling stations.

This paper provides an overview of the challenges of using hydrogen fuel and offers best practices to specify tubing that ensures safe, long-lasting and effective refueling station designs.

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AN ELEMENTARY LOOK AT HYDROGEN

Multiple aspects of hydrogen factor into the difficulties of achieving properly designed refueling stations, such as hydrogen's high energy, small molecule size, flammability and combustibility.

High Energy and Flammability. Hydrogen contains almost three times as much energy per weight as conventional gasoline, making it an attractive fuel, but hydrogen's energy density per volume is very low compared to gasoline and other fuels. The comparatively low energy density per volume means that for effective fuel storage, hydrogen must be stored as a gas at high pressures or in liquid form under extremely low temperatures. And considering hydrogen's high flammability and combustibility as well as the fact that hydrogen flames are nearly invisible, thorough safety considerations are necessary when designing storage and transportation systems.

High-pressure storage and transfer systems are implemented more often than liquid hydrogen alternatives, making tubing that can withstand extremely high pressures necessary. Since hydrogen is colorless, odorless and extremely explosive, high-pressure tubing systems must be designed to minimize leak potential.

Hydrogen Embrittlement. Hydrogen's small atomic size causes damage to many metals through a process called hydrogen embrittlement, also known as hydrogen-assisted cracking or hydrogen-induced cracking (HIC). When hydrogen comes into contact with austenitic stainless steel, it can diffuse into the material and accumulate within the metal's crystal lattice. This can cause the metal to become brittle and prone to cracking — even at stresses that would normally not cause failure.

The mechanism of hydrogen embrittlement is complex. It is thought to be caused by the hydrogen atoms interfering with the movement of dislocations, which are defects in the crystal lattice structure that allow the metal to deform under stress. When hydrogen atoms accumulate at dislocations, movement is prevented. This makes the metal more susceptible to cracking.

HYDROGEN GRADES

Gray: natural gas extraction via steam-methane reforming. This is the world's most common production method.

- Brown/black: coal gasification.
- Purple/pink: electrolysis that is powered by nuclear energy.
- Turquoise: produced by methane pyrolysis, generating solid carbon instead of CO2 emissions.
- Blue: produced from fossil fuels. Similar to gray, black or brown hydrogen, except that CO2 is captured for storage or repurposed.
- Yellow: produced by electrolysis that is powered by grid electricity from a variety of sources.
- White: produced as a byproduct of other industrial processes such as oil refining or fertilizer production.
- Green: produced by water electrolysis that is powered by renewable electricity sources such as wind or solar. This production generates zero CO2 emissions and is the most cost-effective production method.

FIND A HIGH-STRENGTH TUBING SUPPLIER

Seamless coiled tubing provides the advantages of longer length and safe interconnections to remote hydrogen storage and dispensers with only two connections in each tube-run — one at the source and one at the dispenser. Many facilities that transport high-pressure or flammable gases can benefit from long-length, seamless coiled stainless steel tubing.

Our advanced tube manufacturing capability allows us to produce seamless austenitic stainless-steel coils as long as 2900 feet and as smooth as 20 Ra. This ensures we deliver precision-engineered, high-quality tubing that provides hydrogen delivery systems with better safety.

Because our austenitic 316L stainless steel can withstand hydrogen embrittlement without sacrificing flexibility, it is workable enough to bend. And depending on your application's pressures, we cold-work or cold-harden the tubing to withstand up to 1,000 bar (~14,500 psi). Our 316L stainless steel also features high nickel and molybdenum content, which further boosts the tubing's corrosion resistance.

To provide excellent material traceability and ensure our products meet the highest standards, we only use Defense Federal Acquisition Regulation Supplement (DFARS) compliant materials. All coiled tubing is 100-percent eddy current and hydrostatic tested to ensure structural integrity, as well as analyzed for material purity.

The formation of high-pressure hydrogen bubbles within stainless steel can increase the risk of hydrogen embrittlement. When hydrogen diffuses into austenitic stainless steel, it can combine with other elements in the steel such as carbon to form methane or other hydrocarbons. These reactions can produce hydrogen gas within the metal, which can accumulate in small bubbles or voids. If the pressure inside these bubbles increases enough, the metal can crack or fail catastrophically.

High-pressure hydrogen bubbles are more likely to form in areas of the metal where there are high stresses or defects, such as near welds or in areas of the metal where there are sharp changes in geometry or surface roughness. The presence of high-pressure bubbles can increase the metal's susceptibility to hydrogen embrittlement by acting as stress concentration points, increasing the likelihood of the metal cracking.

Hydrogen embrittlement compromises a metal's structural integrity over time. Special material considerations are required to mitigate this effect when designing hydrogen refueling stations.

TUBING DESIGN BEST PRACTICES

When designing the plumbing systems for hydrogen refueling stations and other transport infrastructure, it is crucial to specify tubing that withstands hydrogen embrittlement and minimizes the potential for leaks and other structural failures. Here are some considerations:

SELECT THE RIGHT MATERIAL

Embrittlement-resistant metals provide the protection necessary to minimize the harmful effects of hydrogen, which often diffuses into steel, aluminum and titanium. Stainless steels generally provide better protection due to their high chromium content. 316L austenitic stainless steel is an alloy that provides the greatest balance between embrittlement protection and cost — making it ideal for hydrogen fuel applications.

Additionally, this type of stainless steel benefits from excellent corrosion resistance. Many hydrogen fuel lines are placed underground or in similar environments that simplify a design, allowing transport between storage and dispensers with fewer tube fittings and supports. While this configuration reduces the number of joints, it increases the likelihood of corrosion. Tubing with high corrosion resistance will be able to withstand such harsh conditions longer.

ELIMINATE WELDS

Hydrogen is typically stored at pressures up to 10,000 psi, which is much higher than storage pressures for natural gas or gasoline. These extreme pressures make leak prevention an additional design priority for hydrogen refueling stations. Typically, the plumbing systems of these refueling stations consist of tubes connected by welds, fittings and other connections — all of which are potential leak sites.

A design strategy that reduces leak potential minimizes the number of tubing sections, thereby reducing the total of necessary welds. Following this strategy, hydrogen refueling stations should incorporate long-length tubing, minimizing leak potential and ensuring greater safety and successful operation. Additionally, long lengths of seamless tubing simplify designs, reducing installation time and maintenance efforts since there are far fewer welds to perform or inspect.

YOUR TUBING SUPPLIER CAN HELP

Since hydrogen is a relatively new fuel source, many engineers lack extensive experience and familiarity with designing and specifying the proper infrastructure. Regulations are being developed to standardize hydrogen fuel applications. In the meantime, it's important to understand your application's requirements and work with your supplier to properly specify the best tubing solution.

Contact us for more information.

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