Sealing the future of hydrogen pipelines

Ian Kinnear, GPT Industries, USA, discusses understanding and overcoming the challenges of sealing and protecting hydrogen pipelines.

With every new development, there will always be unknowns and challenges that come along with making the development a reality. When exploring sealing and protecting hydrogen pipelines, GPT Industries has been able to identify many critical, unique challenges that will come along with it. These challenges will need to be addressed to make our systems as safe and known as possible as we progress into more of a hydrogen future. For the focus of GPT, this future is specific to looking into the transportation of hydrogen, specifically through pipelines. This article will delve into the future of hydrogen energy, specifically being transported through pipelines, and then detail the challenges in terms of sealing and protecting these pipelines and some possible solutions to overcome these.

Hydrogen is light, making it easier to transport and work with in general. It is storable, which is a critical factor when considering any form of sustainable energy. When used in a fuel cell, hydrogen is considered energy dense, meaning there is high energy content per unit of weight. Hydrogen produces no direct emissions of pollutants or greenhouse gases when used as an energy source (producing the hydrogen can be a different story). Lastly, hydrogen can be produced from diverse resources, as we know that it is abundant in our universe, meaning that we just need to be able to produce it effectively to form energy in a renewable way. Because of all these reasons, the forecast for hydrogen demand worldwide is exponential over the next 45 years. According to Statista, in 2019 the demand for hydrogen across various sectors was 71 million t. Come 2030 that will be 87.2 million t, 2050 287 million t, and 2070 519.1 million t. This is across the sectors of refining, power, buildings, synfuel production, ammonia production, transportation, and industry.

Future of hydrogen transportation

A critical factor to keeping up with this increasing demand for hydrogen to become an energy source will be the effectiveness of transportation. A huge plus of fossil fuels is that we can transport them extremely efficiently. The way this is most efficiently done is through pipelines. Regarding hydrogen, Energy.gov states that "Key challenges to hydrogen delivery include reducing cost, increasing energy efficiency, maintaining hydrogen purity, and minimising hydrogen leakage." These challenges are directly in line pipelines, which are the most efficient, lowest cost, and lowest emission way to traditionally transport energy sources. Continuing, Energy. gov states "Today, hydrogen is transported from the point of production to the point of use via pipeline and over the road in cryogenic liquid tanker trucks or gaseous tube trailers. Pipelines are deployed in regions with substantial demand (hundreds of tpd) that is expected to remain stable for decades." As seen by the forecast in Figure 1, there is sustainable hydrogen demand in the coming years, meaning that transport through pipelines is a likely means of hydrogen transportation. In addition to this, millions of kilometers of natural gas pipelines are already in place, so the infrastructure for this transportation already exists and can likely be utilised to make this means of transport more effective and efficient. Pipelines will be essential in the process of bringing hydrogen to be a new, reliable energy source, and thus needs to be considered in the process of hydrogen growth.

With this evidence present and movement happening before our eyes, the time to focus on this growth is now. As an industry, however, there are still huge roadblocks in front of us. Testing and regulation on hydrogen pipelines and sealing is very limited. It is always a challenge to have caught up on the regulation side before anything has been put into action. With hydrogen specifically, however, there are both real and perceived implications in terms of danger that must be strongly considered. The perceived dangers are based upon real incidents, such as the Hindenburg, that have highlighted the power hydrogen can produce. In the transportation of hydrogen, there is no leeway for something to go wrong.

Sealing hydrogen in pipelines is going to bring unique challenges that must be addressed and done so in a way that brings confidence, even before regulations have been set for hydrogen transportation. In working through many sealing applications, GPT has identified these challenges to sealing and protecting hydrogen pipelines specifically. Some of these are similar to what is faced in the traditional oil and gas markets, but some are very unique and new to be accounted for with hydrogen. Each of these challenges will be explained further throughout this paper. The first challenge to discuss is sealing capabilities, as hydrogen is incredibly difficult to seal. Next are the challenges that come from permeation, uniquely emphasised by hydrogen. Next is hydrogen's propensity for ignition, potentially leading to fire and explosion, a reason why there is danger with utilising hydrogen. Chemical compatibly is also a challenge, as we need to ensure the correct materials are being used for long term success. All of these are in combination at the same time as well, meaning solutions must check all the boxes to provide the safety required for these applications.

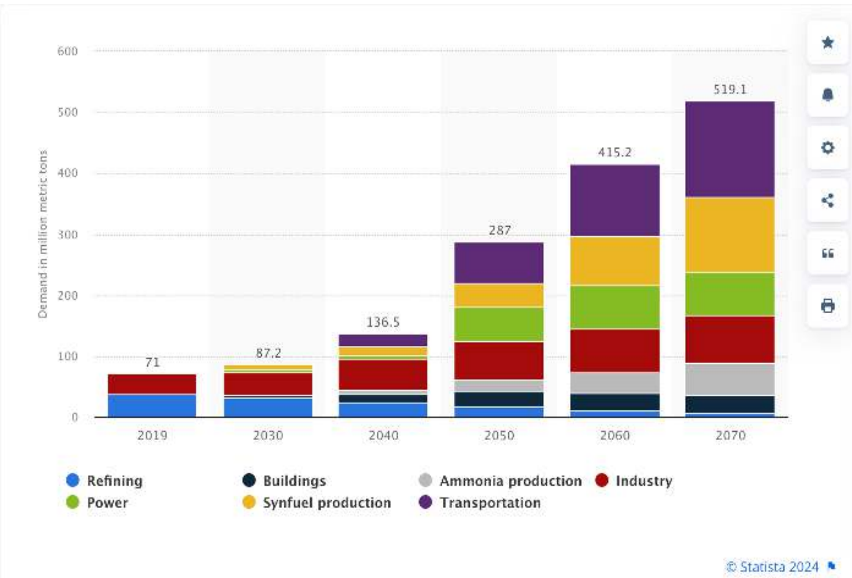

Figure 1. Global demand for hydrogen by sector to 2070. (Aizarani, J. (2023, February 17). Statista. Retrieved 4 May 2023, from https://www.statista.com/statistics/760001/global-hydrogen-demand-by-sector-sustainable-scenario/)

Main challenges of sealing hydrogen pipelines

Looking at the challenges around sealing capabilities, hydrogen has a much higher propensity to leak than traditional medias, especially the ones that the oil and gas industry traditionally deal with. The reason for this is because hydrogen uniquely provides low viscosity, very high diffusivity, a high likelihood of embrittlement (more on this later), all because it is the smallest molecule gas. When attempting to seal the smallest molecule gas, the margin for error will be at the lowest point. To understand this further, we can look at the diffusion coefficient of various common sealing materials when comparing methane and hydrogen to give further perspective. This coefficient is essentially how easily the media will move from a high concentration region to a low concentration region, something that cannot happen when achieving a seal. Through FKM Type 1 and traditional PTFE, two of the most common sealing materials, the diffusion coefficient for methane is 1.4 for FKM Type 1 and 1.7 for PTFE. When comparing this to hydrogen, the diffusion coefficient for FKM Type 1 goes to 14.1 and for PTFE goes to 11.3. This is a 907% increase in diffusion coefficient of hydrogen going through FKM Type 1 instead of methane, and a 565% increase for PTFE. As a pinch test, it is obvious that sealing a small molecule is going to be more challenging than larger molecules, but this is evidence for how traditional sealing materials will fare in this regard. The actual act of sealing the hydrogen media in pipeline connections will be a challenge in the future transport of hydrogen.

Permeation is the next major challenge specific to hydrogen. Speaking again on the point that hydrogen is the smallest molecule gas, this leads to it being able to permeate into and through materials much more frequently. In the world of sealing, permeation can lead to two major challenges. The first is that permeation can lead to a direct leak through the material itself, so that even if a proper seal is made, leaks are still occurring through the material. This is very similar to the diffusion coefficients that were recently shared, as diffusion and permeation are closely related. In traditional pipeline sealing, leaks due to permeation are already experienced, which is why metal cores have needed to be introduced to traditional isolation gaskets. This permeation leads to higher levels of emissions taking place, especially when dealing with hydrogen in the pipeline. Sealing materials that are not permeable will be critical, which typically leads to metals being used. However, metals can be challenging because of the next permeability point, which is the likelihood of embrittlement.

When hydrogen permeates into a metal, it can cause embrittlement, or the decrease of ductility of the material. The typical forms that this occurs from hydrogen are mechanical stress cracking, hydrogen included cracking, stress-oriented hydrogen induced cracking, and high temperature hydrogen damage. Diffuse hydrogen atoms can enter a metal's surface and then combine within causing cracking and brittleness within the metal. Embrittlement will most likely happen within metals and are more susceptible in some metals than others. The rub lies in that metallic seals are more likely to be used to avoid emissions from permeation through the material and diffusion through elastomers. However, these metals are now susceptible to embrittlement, where hydrogen is absorbed by the metal, reducing its yield strength, and leading to premature failure. Finding materials that can hold up to both permeation impacts is a challenge.

The next challenge from transportation of hydrogen in pipelines is hydrogen's propensity for ignition, which can lead to fire and explosion. The reason that hydrogen provides such a concern in terms of fire and explosion is because of its very wide flammability range, making ignition or combustion easier. This is combined with a very low ignition energy and the possibility of spontaneous ignition. If this occurs, hydrogen can also burn with an invisible flame, making it even more dangerous. This leads to the need for a fire safe seal. With a pipeline full of hydrogen travelling through it, if an external fire happens to occur and the seals fail, hydrogen will begin leaking onto an already existing fire, which can lead to a very dangerous situation. A seal that can hold up in a fire for long enough time for the fire to either be extinguished or for the line to be shut off is essential for safety concerns when transporting hydrogen.

The production of hydrogen can come from various sources, highlighted by the different types of hydrogen, such as grey, blue, green, etc. With these various types of hydrogen production, there is the potential for hydrogen applications to provide various challenging medias in the process, leading for the sealing materials to be chemically compatible throughout. Hydrogen itself can be a challenging media when exposed in soak testing for various seal materials, as it can lower the material properties of many elastomers. Along with this, there are times where other medias such as CO2, amines, steam, H2S, ammonia, and others can be present in the process. These medias can cause major challenges with traditional sealing materials, whether they be metals, elastomers, sheet materials, or anything else that is used as a gasket.

Potential solution for sealing hydrogen pipelines

With all these challenges laid out, it becomes very challenging to find a seal that can meet all the criteria required. GPT Industries however feels that its Evolution gasket is created fit for purpose for hydrogen applications and can overcome the challenges that hydrogen transportation brings from a sealing perspective. Evolution utilises a metal core, so there is no permeable material for hydrogen to leak through and cause emissions. With this being said, there is also no exposed metal, as the gasket is completely encapsulated with coating, and the sealing occurs directly at the ID with a reinforced PTFE ID seal, leading to embrittlement also not being a concern. Evolution is a low emission sealing gasket, due to its two-seal, one metallic, one elastomeric design, which provides levels of sealing redundancy. This is shown in testing such as Shell Tightness Class A or Chevron Fugitive Emissions testing of only allowing 1 PPmv leakage. Much of this testing is done with small molecule gas, showing that Evolution will be the low emission seal needed for hydrogen. It is also inherently fire safe, passing multiple sizes and pressure classes of the API 6FB fire test. The reinforced PTFE ID seal provides chemical compatibility towards all medias discussed, with seal options that have been BAM testing in hydrogen storage, in both liquid and gas forms. This is the seal that is set to be the future of hydrogen transportation, providing the highest level of safety by checking all the necessary boxes. The future of energy will have hydrogen being high importance, and GPT is here to help.

Figure 2. GPT's Evolution gasket.