DuPont™ Vespel® Parts for Hydrogen Energy

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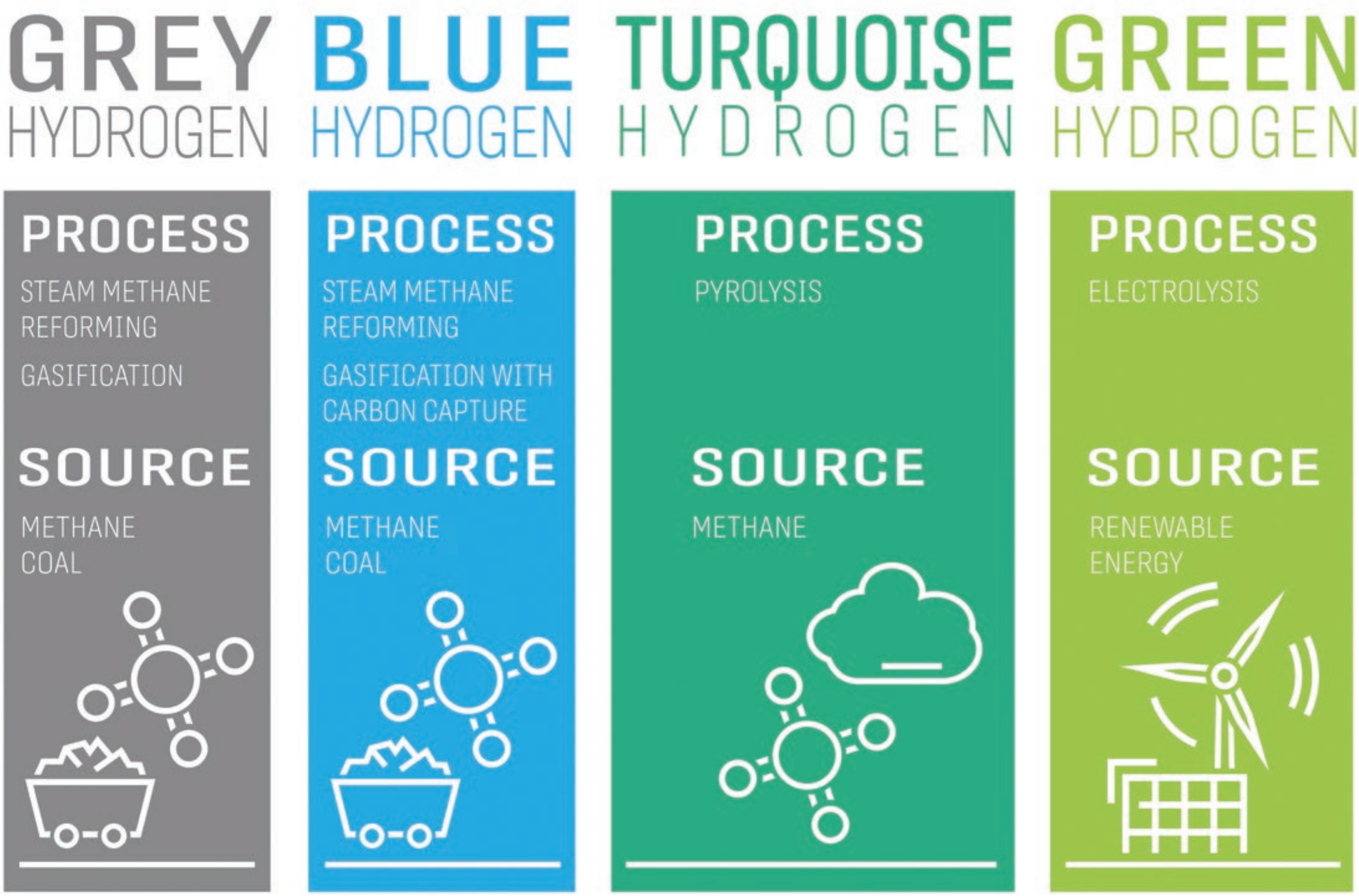
Introduction

Given the current environmental challenges linked to greenhouse gas emissions, hydrogen has the potential to become an important source of clean energy. Hydrogen has the benefit of only generating water as a byproduct when combusted for energy and can be used in applications such as electric fuel cell vehicles or as a source for heating.

However, large-scale, economical production of hydrogen itself without the generation of greenhouse gases is still a challenge. The most common method of producing hydrogen, often referred to as grey hydrogen, involves decarbonating methane using steam methane reforming. This process releases CO_2 as a byproduct. To make this process cleaner, technology is being developed to capture the CO_2 generated. With this added step, this type of production is often referred to as blue hydrogen. Alternative processes that eliminate the creation of CO_2 during hydrogen production are also being developed. These processes are referred to as green hydrogen, and generally refer to the production of hydrogen through the electrolysis of water via a renewable energy source. The byproduct of this process is simply oxygen, thus eliminating emissions of any greenhouse gases.

Types of Hydrogen Production



Challenges of using hydrogen as new energy source

Widespread adoption of hydrogen as an alternative energy source brings about a set of requirements different from those of fossil fuels. Designing safe, efficient, and environmentally- friendly processes for the production, conversion, transportation, and supply of hydrogen is critical.

Storage and Transportation

Hydrogen's volumetric energy density is extremely low compared to other fuels. Therefore, to be a practical fuel source its energy density must be increased. This is commonly achieved by either compressing hydrogen gas to pressures between 350-700 bar, or by liquifying hydrogen by cooling it to -253 °C at atmospheric pressure. In both of these states hydrogen's volume is reduced to a more reasonable size for storage and transport. However, maintaining hydrogen as a liquid or compressed gas can be difficult. Tanks with proper thermal insulation or active cooling systems are necessary to keep hydrogen in its liquid state for extended periods of time.

Furthermore, systems must balance both efficiency and cost effectiveness, a particularly complicated challenge due to the significant temperature variation produced by rapid pressure change during hydrogen transfer and dispensing.

Safety

Hydrogen is highly reactive and can ignite in air at concentrations as low as 4%. Due to this, safety is a concern if uncontrolled hydrogen leakage occurs.

Because of its low molecular weight and size, hydrogen molecules can permeate through most materials, including metals, leading to cracks. This phenomenon, called hydrogen embrittlement, can significantly reduce the ductility of solid metals and is common when metals are in contact with hydrogen at variable high pressures.

Hydrogen as a fuel for transportation

In transportation, hydrogen can be utilized in both fuel cell electric vehicles (FCEVs) and hydrogen internal combustion engines (H_2 ICE). These technologies can either use liquid hydrogen, stored at cryogenic temperatures, or compressed hydrogen gas. In trucks and passenger vehicles, both FCEVs and H2 ICEs commonly utilize compressed hydrogen gas stored at high pressures (either 350 or 750 bar). In aviation, while both FCEVs and H_2 ICE are being considered as future technologies, liquid hydrogen is particularly attractive. It is a high-potential fuel for zero-emission aircraft as it has specific energy-per-mass that is three times higher than traditional jet fuel. This is crucial for aviation, where maximizing the amount of fuel stored while minimizing weight and space is essential for achieving longer flight ranges.

To store, transport and convert hydrogen from liquid to gas for use in these systems, components such as valves, pressure reducers, compressors, and pumps are essential. DuPont™ Vespel® parts and shapes have a proven track record of enabling safe and efficient operation of these components in demanding hydrogen environments such as those with cryogenic or high-pressure conditions.

DuPont™ Vespel® Polyimide Parts

DuPont™ Vespel® is the brand name for a range of high performance, mainly polyimide-based plastics. Vespel® SP polyimide was originally developed in cooperation with NASA for the Apollo Space Project.

Over the past 60 years, the Vespel® parts and shapes portfolio has expanded to include a variety of different grades, each with unique performance characteristics accomplished by varying the types and levels of fillers and different manufacturing methods for parts or shapes. Vespel® parts and shapes are resistant to heat, creep, wear and a variety of chemicals, making them well-suited solutions for the applications of compressing, transporting, and storing hydrogen.

Key Properties of DuPont™ Vespel® Parts for Hydrogen Sealing and Storage

Low and consistent modulus and higher mechanical resistance

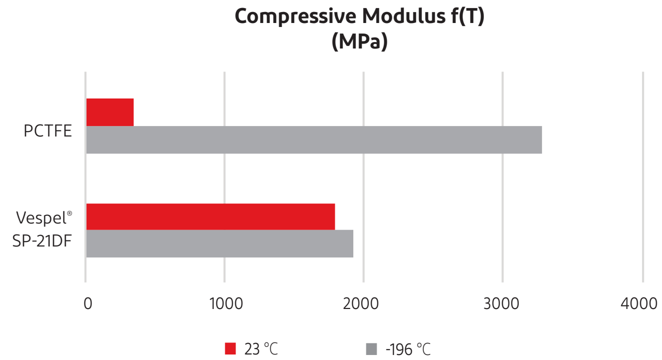
The "soft but strong" behavior of Vespel® is a key advantage in cryogenic and hydrogen valve applications, where it is necessary to maintain sealing performance at low temperatures.

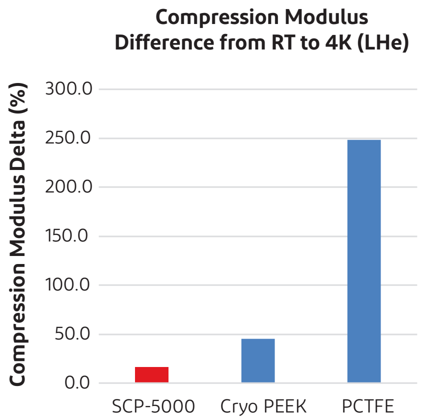
To obtain an excellent seal for hydrogen applications, the seal must perform well in both cryogenic and elevated temperatures. It must withstand sudden changes in temperature, pressure, and hydrogen flow velocity while maintaining its mechanical properties.

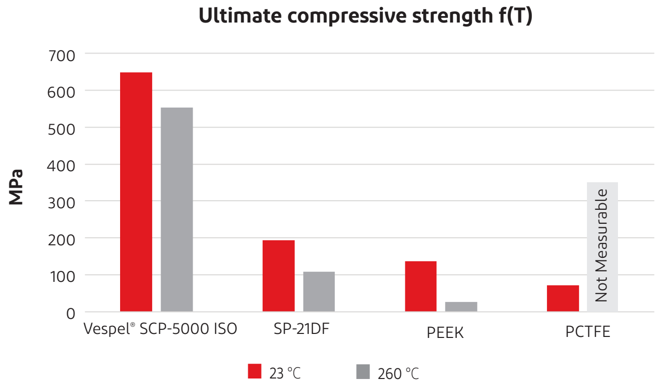
The elastic modulus of Vespel® is very stable at temperatures ranging from ambient to cryogenic temperatures, unlike other polymers such as PEEK and PCTFE, which lose elasticity and exhibit significant changes in their mechanical properties. If the modulus changes drastically, the seal might not compress properly, leading to potential gaps or leaks. A stable modulus helps ensure that the seal maintains appropriate compressive force and stress distribution, preserving the integrity of the seal.

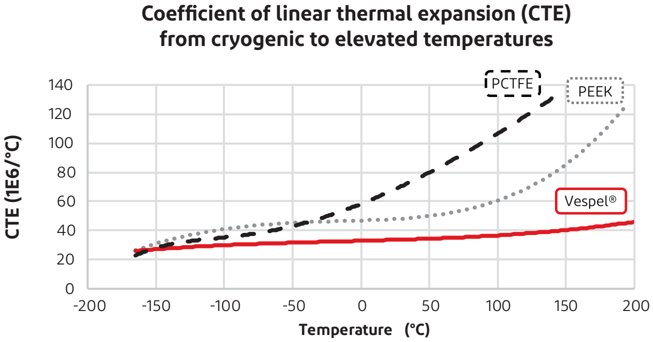
In addition, Vespel® parts offer better ultimate pressure resistance than PEEK and PCTFE from cryogenic up to elevated temperatures, providing an additional critical safety buffer for the system and increasing the operational temperature range.

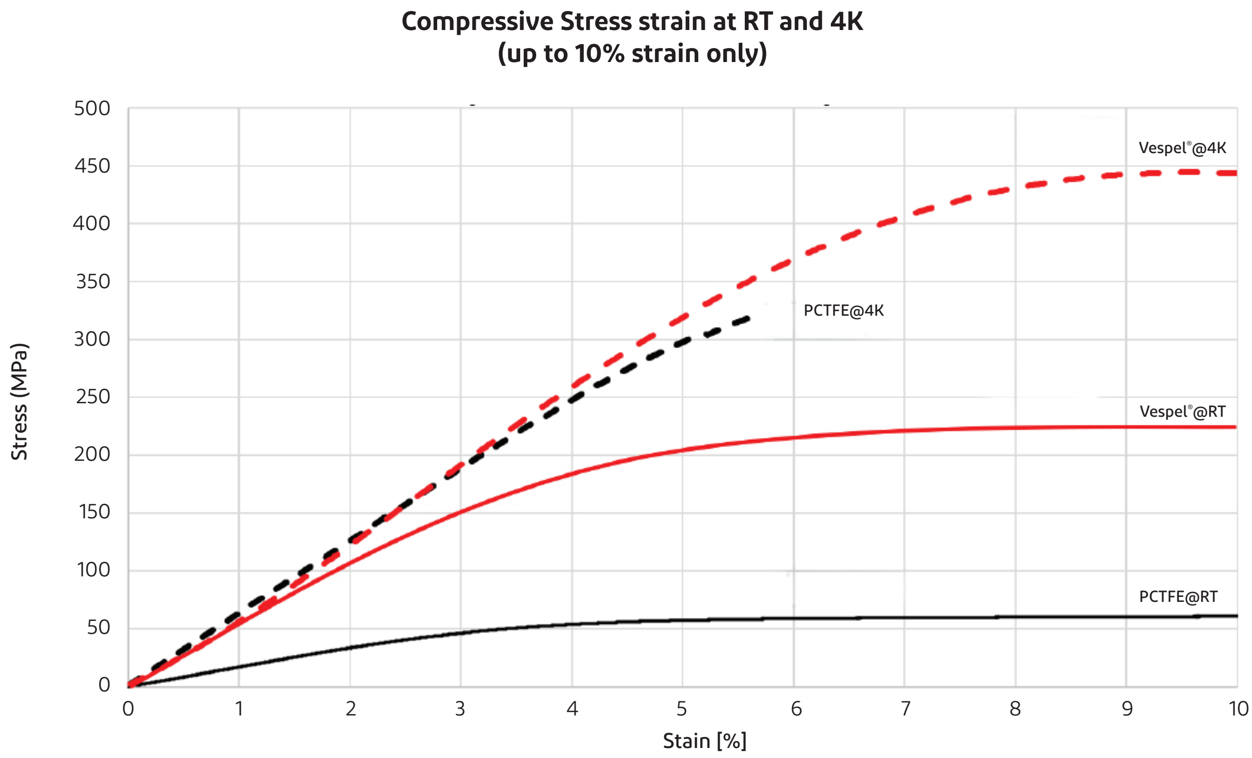
Thermal expansion can significantly affect the performance of sealing materials and influence the effectiveness of the seal in various ways. A change in coefficient of linear thermal expansion (CTE) leads to uneven dimensional changes, internal stresses, and accelerated creep. The uniform CTE of Vespel® parts over a wide temperature range helps to maintain a tight seal over a long lifetime.











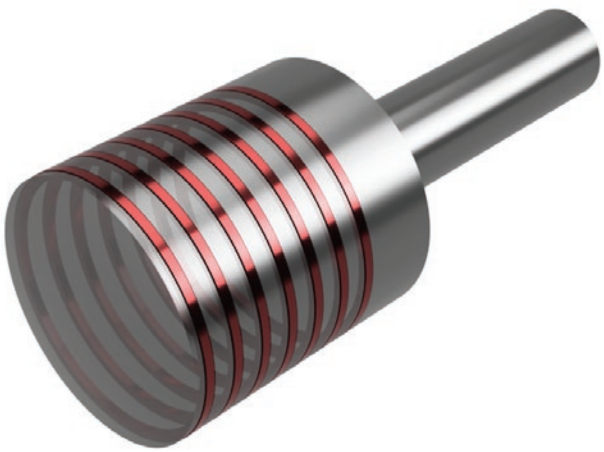
Materials with high elongation and toughness can offer significant benefits in cryogenic applications by improving sealing performance, compensating for thermal contraction, reducing brittleness, improving elasticity and maintaining flexibility. Vespel® SCP-5000 ISO showed only a slight increase in compressive modulus from room temperature RT to cryogenic conditions at 4K, while maintaining a high elastic range of more than 400 MPa and offering improved toughness.

Case Study: Vespel® for Piston Rings and Valve Seats in Cryopumps

Featured Products: Vespel® SP-21, SP-1, and SCP-50094
Typical challenges for sealing in hydrogen environments are based on three primary factors: pressure, temperature, and hydrogen concentration, all of which can vary greatly when being transformed from one phase to another.

Some hydrogen filling stations store liquid hydrogen, which must be converted to gas for fueling trucks or cars. This can be accomplished using a cryopump containing piston rings made with Vespel® SP-21 and vale seats made with Vespel® SP-1 for effective sealing. Vespel® polyimide is designed to withstand extreme service conditions in both liquid and gaseous states, providing increased reliability, safety, and extended operating lifetimes while meeting demanding tribological requirements.

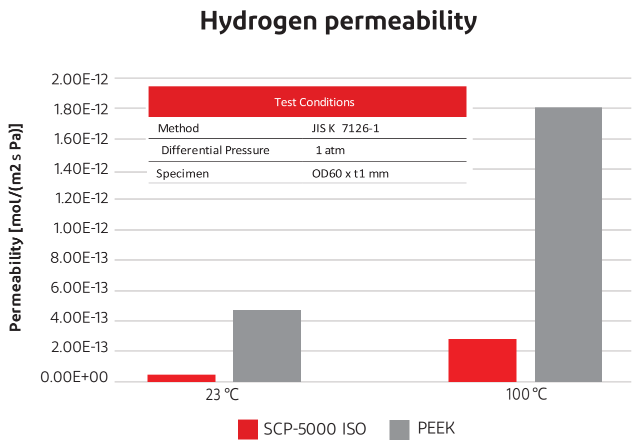
In both gaseous and liquid hydrogen environments, Vespel® polyimide exhibits reduced friction and wear rates, achieving excellent performance in liquid hydrogen. These attributes contribute to efficient pump technology that minimizes energy costs, reduces hydrogen loss, and extends the cryopump's operational lifespan.



Low hydrogen permeability

Hydrogen permeability is a key material property to establish if a polymer can properly store hydrogen over a long period of time. The lower the permeability, the better the material's ability to contain hydrogen and avoid leaking.

When compared to PEEK in similar conditions, Vespel® Polyimide Parts show significantly lower hydrogen permeability, even at elevated temperatures.



Hydrogen permeation tests were performed via gas chromatography using a differential pressure method.

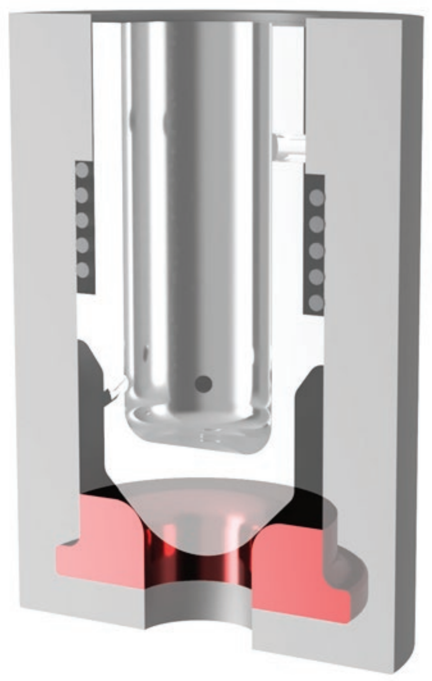
Test Conditions
Method: Proprietary test method of Kyushu University
Differential pressure: 900 bar
Temperature: RT
Specimen: 1.5 mm thickness

Case Study: Vespel® polyimide for Sealing Elements in On-Tank Valves & Pressure Regulators

Featured Products: Vespel® SCP-5000 & SP-1
On tank valves (OTV) are fitted directly to a hydrogen storage tank and are used to control and regulate the flow of hydrogen gas into and out of the tank. They need to reliably close and open to prevent accidental release or exposure, maintain operation within safe operating limits and prevent over pressurization.

On tank valves must have high-quality sealing mechanisms that can withstand high pressures of 350 or 700 bar with excursions of > 1050 bar without failure or leakage. Proper sealing is critical as even small leaks can lead to significant hazards due to hydrogen's low ignition energy and wide flammability range.

Vespel® SCP-5000 and SP-1 parts offer unique properties which make them well-suited for these critical sealing applications that require high compressive strength and outstanding creep resistance, best in class hydrogen permeability resistance, a broad operational temperature range, ductile behavior and compliance to hydrogen standards. These features provide long-term, leak-proof, safe containment and distribution of the hydrogen as well as long-lasting and durable operating performance throughout the vehicle's service life.

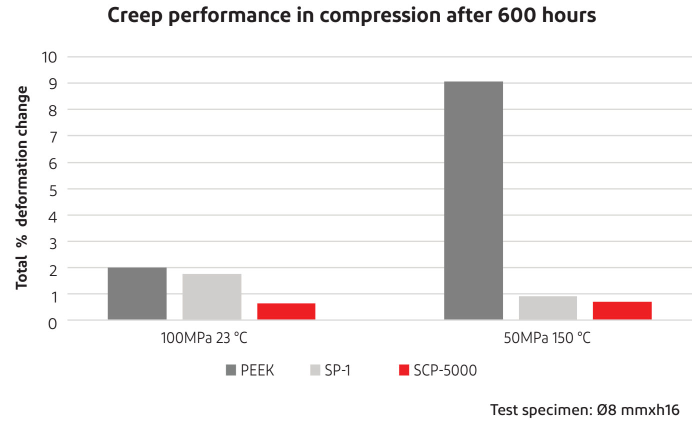


Key properties of Vespel® polyimide parts for Operational Efficiency

Creep

Hydrogen leaks largely originate from deformed seals or gaskets. Therefore, materials used in sealing elements should display excellent creep performance.

Vespel® exhibits high dimensional stability, maintaining its sealing performance over a long service lifetime.



Wear and Friction

Valves require low friction to actuate properly. This is even more important in cryogenic environments of many hydrogen applications. Due to its low coefficient of friction, Vespel® can help reduce actuation force, helping to reduce energy consumption.

In addition, the low wear rate of Vespel® in hydrogen is an important property which helps ensure the long service life of the valve, contributing to less frequent maintenance.

The same characteristics are also beneficial for pumps and compressors in terms of operational efficiency improvement and potential reduction of energy consumption.

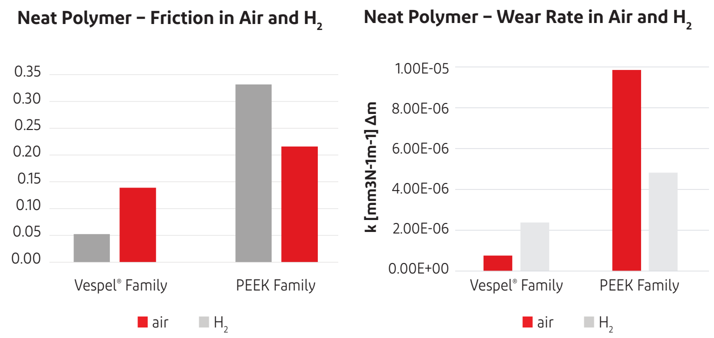


Fig 1.: COF and Wear and friction for neat polymers of the Vespel® and PEEK Family, data generated by the BAM Bundestanstalt für Materialforschung und –prüfung by Mrs. Theiler, Counterface AISI 304, Ra ~ 0.2 μm, sliding speed v = 0.2 m/s, contact pressure 3 MPa.

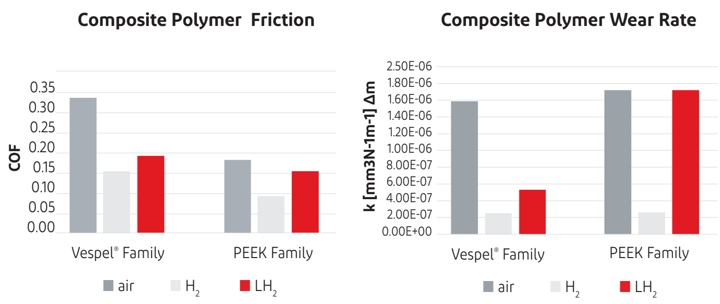
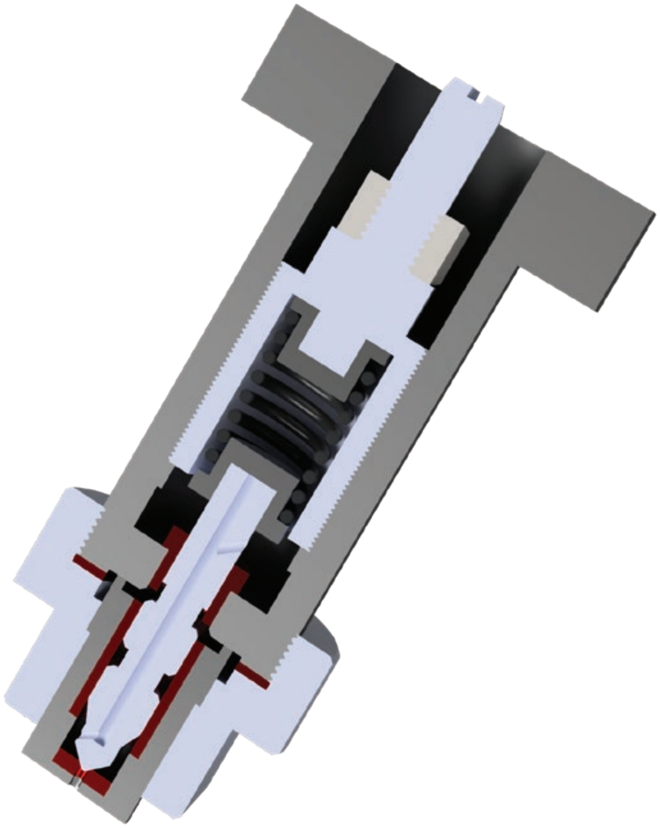


Fig 2: COF and Wear and friction for composite polymers of the Vespel® and PEEK Family, data generated by the BAM Bundestanstalt für Materialforschung und –prüfung by Mrs. Theiler, Counterface AISI 304, Ra ~ 0.2 μm, sliding speed v = 0.2 m/s, contact pressure 3 MPa.

Potential application: Vespel® polyimide parts for Pressure Reducers & Injectors in Hydrogen Internal Combustion Engines

Featured Products: Vespel® SP-1, SCP-50094, and SCP-5050
In addition to fuel cell electric vehicles (FCEVs), hydrogen vehicles powered by internal combustion engines (H_2 ICE) are also growing in popularity. These engines emit almost no CO_2 and are considered promising for heavy-duty trucks and other off-road equipment.

They are considered to run dry since they are without a lubricating diesel, and therefore face substantial wear and friction challenges. Two key components of hydrogen internal combustion engines particularly affected are injectors and pressure reducers, which deliver a precise volume of hydrogen to the combustion chamber at the desired pressure. With excellent tribological properties and high-temperature resistance, Vespel® polyimide parts meet these challenges by supporting reliable sealing of the injectors and the combustion chamber. Vespel® bushings and seal elements enable effective functioning of H_2 injectors and pressure reducers, providing sealing without lubrication, even near the combustion chamber, meeting rigorous demands of the application.



Summary

Vespel® polyimide is the answer to the most stringent sealing requirements in hydrogen applications, thanks to its unique blend of thermal, mechanical, and tribological properties.

Challenges in hydrogen applications		Vespel® solutions
Bubble tight sealing from elevated down to cryogenic temperatures	→	**A low and consistent compressive modulus,** and high mechanical resistance, offering exceptional sealing in a variety of typical H_2 conditions
Potential permeability issues during storage, due to low molecular weight of hydrogen	→	**Significantly lower H_2 permeability than materials like PEEK** across a wide range of temperatures and pressures
Service life under high loads in wide temperature ranges, from elevated down to cryogenic	→	**Excellent creep performance** at high loads and elevated temperatures, "**soft but strong**" characteristics for soft sealing at low temperatures
Demanding tribological requirements, efficiency and service life	→	**Low COF in air and hydrogen**, helping to reduce actuation force and improve operational efficiency /reduce energy consumption
Costly maintenance	→	**Low wear rate** that contributes to lowering the frequency at which components need replacement

Vespel® polyimide: the well-suited blend of properties to generate value in hydrogen applications

Key Vespel® Applications		
Valves and Pressure Reducers	Pumps	Compressors
Vespel® S	**Vespel® S and CR**	**Vespel® CR**
Seats	Bearings	Piston Rings
Stem Packing	Wear Rings	Rider Bands
Seat Carrier Seals	Piston Ring	Labyrinth Seals
Hydrogen Receptacles	Bushings	Packing Rings
Connectors		Valve Plates
Industrial and transportation applications, from production to mobility	Pipelines, storage, refueling	Production, storage, pipeline, refueling

Grade Selector Vespel® S for static and dynamic wear and sealing applications:

	Liquid hydrogen	Compressed gaseous hydrogen Low P	Compressed gaseous hydrogen High P
Static (e.g. Valve seats)	SP-1 SCP-5000	SP-1	SCP-5000
Dynamic (e.g. Piston seal rings)	SCP-5050 SCP-50094 SP-21	SP-21	SCP-50094

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