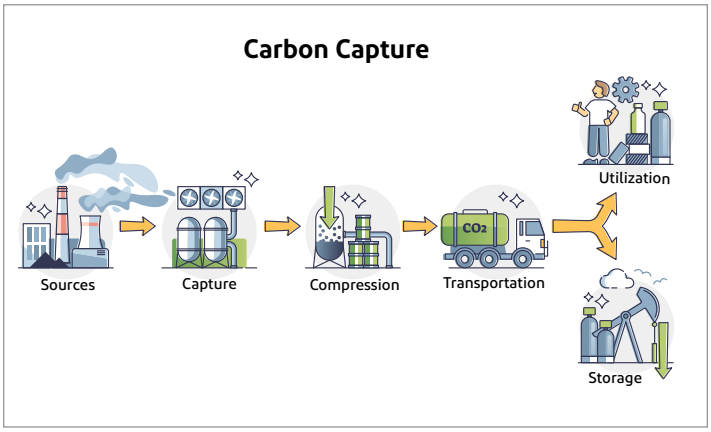
ENERGY

DuPont™ Kalrez® and Vespel® for Carbon Capture Utilization & Storage

DuPont™ Kalrez® and Vespel® parts deliver performance, reliability and safety where it matters most

The DuPont™ Kalrez® and Vespel® portfolio offers a range of high-performance parts and testing capabilities. This enables customers to meet the most stringent industry standards in terms of reliability, safety, traceability, and efficiency for critical applications in high pressure and high temperature environments.

Carbon Capture, Utilization and Storage (CCUS) refers to a suite of technologies that can play a diverse role in meeting global energy and climate goals.



CCUS involves the capture of CO_2 from large point sources, such as power generation or industrial facilities, that use either fossil fuels or biomass as fuel. CO_2 can also be captured directly from the atmosphere. If not being used on-site, the captured CO_2 can be compressed and transported by pipeline, ship, rail or truck to be used in a range of applications or injected into deep geological formations, including depleted oil and gas reservoirs or saline aquifers, which can trap the CO_2 for permanent storage (Source: IEA).

Carbon Capture Utilization and Storage process

The carbon capture utilization and storage is a plural steps process. The objective is to remove existing CO_2 or prevent CO_2 from entering the atmosphere. There are four main steps.

1. **Capture:** CO_2 captured from large point sources.

   Several separation technologies can be used to do the carbon scrubbing. The current dominant technology is the amine chemical absorption. Other technologies include membrane, adsorption, calcium looping and cryogenic.

   This step requires the sealing products to work in an environment combining amines and elevated temperature. These are the demanding conditions where Kalrez® Spectrum™ 6380 and Vespel® CR-6100 parts are used to deliver outstanding performance.

2. **Compression and Transportation:** Compressed CO_2 transported to storage point or transformed into a usable product.

   This step involves compressing CO_2 and transporting it through a series of equipment, such as valves, pumps, compressors, pipes and couplings. Compressed CO_2 may also be in the supercritical phase with elevated pressure and temperature.

   Seals require high pressure sealing performance and potentially rapid gas decompression resistance. Kalrez® 0090 and Kalrez® OG193 could be used in this service.

3. **Storage:** CO_2 injection into underground geological formations.

   This step, which is also called geo-sequestration, consists of injecting CO_2 into geological formation. High pressure CO_2 gas is involved and both Kalrez® 0090 and Kalrez® OG193 could be used in this application.

4. **Utilization:** Usage of CO_2 into products or services.

   Approximately 230 Mt of CO_2 are currently used each year, mainly in the fertilizer industry for urea manufacturing and for injection into oil field for enhanced oil recovery (EOR). The new utilization examples are the production of CO_2-based synthetic fuels, chemicals and building aggregates (Source: IEA).

   These uses could involve handling of CO_2 at high pressure and different temperatures but also combined with other chemicals where Kalrez® materials can offer value and performance.

CCUS technologies

While CCUS technology is not new, existing technology experienced scalability and cost issues.

Development of next generation technologies are underway. Some have been tested, yet most still require more extensive testing.

Capture technologies include, but are not limited to:

- Absorption
- Physical solvent absorption
- Cryogenic
- Membrane

Chemical absorption technology with amine appears to be the most common process used today in the industry.

Kalrez® solutions for CCUS

There are three main attributes that Kalrez® can bring to CCUS:

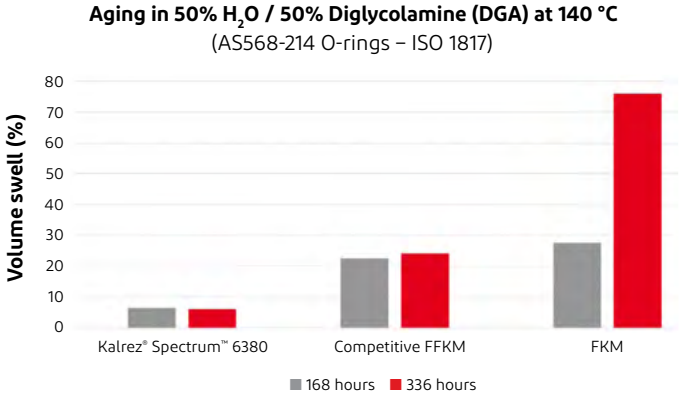
- Capture process – chemical resistance to amine for the CO_2 absorption process
- Transport and Utilization process – compatibility with sCO_2
- Transport and Utilization process – Rapid Gas Decompression (RGD) resistance with gas CO_2

For the rapid gas decompression resistance to CO_2, different conditions can be of interest:

1. **RGD Resistance at high decompression rates**, tested with 12 MPa/min decompression rate, 200 bar max pressure and 200 °C max temperature
2. **RGD Cycle Resistance**, tested with 150 bar max pressure and 100 °C temperature

Chemical Resistance to Amine

In order to assess the chemical resistance to amines Kalrez® Spectrum™ 6380 has been tested in Diglycolamine (DGA), an amine which is used for chemical absorption process of H_2S in gas sweetening plants. Results indicate that Kalrez® Spectrum™ 6380 exhibits significantly lower swelling compared to FKM and compared to other FFKM.



Thanks to its lower sensitivity to amines, Kalrez® Spectrum™ 6380 is already used for sealing applications in processes to eliminate hydrogen sulfide from natural gas in refineries. It could also be an excellent material for sealing applications in the CO_2 absorption process requiring amine resistance.*

* Reference: KZE-A40122-00-0622 available on DuPont™ Kalrez® online resource center

Compatibility with supercritical CO_2

Supercritical CO_2 (sCO_2) is a state of carbon dioxide, where it possesses fluid-like density but gas-like diffusivity properties. This state occurs when the CO_2 is above its critical point (typically 31 °C and 73 bar).

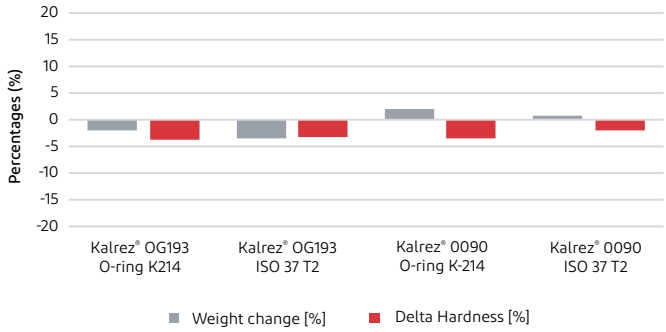
Transporting sCO_2 is the standard practice of the industry. It has advantages over transporting gaseous CO_2 due to its flowability and it is more suitable for injecting into porous rock for EOR. For this reason, a compatibility test has been developed to assess the potential influence on Kalrez® parts.

In this test, Kalrez® OG193 and Kalrez® 0090 O-rings were soaked for two weeks in pure sCO_2. After the test, a low decompression rate was applied to avoid additional RGD effect (decompression rate was kept below 1 MPa/min).

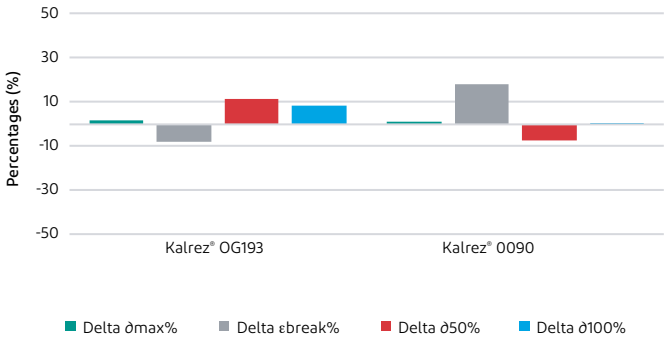
Test conditions	
Grades	Kalrez® 0090 and OG193
Gas	100% CO_2
Pressure	200 bar / 2,900 psi
Temperature	200 °C / 392 °F
Specimen	O-ring K-214 (24.99x3.53mm) & Tensile ISO 37 T2
Hold time	336 hours
Cycle	1
Decompression rate	minimum (< 1 MPa/min)

The hardness properties, volume change and tensile properties have been evaluated before and after sCO_2 exposure. The acceptance criteria of ISO 23936-2 was used to determine if the Kalrez® 0090 and OG193 with sCO_2 offered acceptable compatibility.

Weight and hardness change after 336 hours immersion in 100% CO_2 at 2,900 psi and 200 °C (392 °F) for unconstrained samples



Tensile property change on ISO 37 T2 specimen after 336 hours immersion in 100% CO_2 at 2,900 psi and 200 °C (392 °F) for unconstrained samples



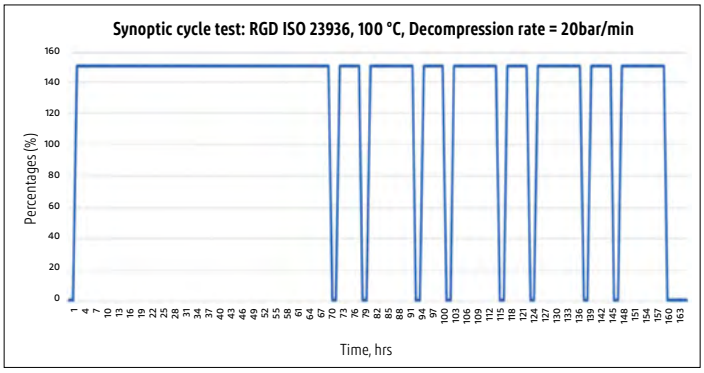
Based on the acceptance criteria of the ISO 23936-2, both compounds passed the ageing test with no significant property loss.

Rapid gas decompression (RGD) resistance in CO_2

Transportation, Utilization and Storage require high pressure sealing of CO_2 combined with rapid gas decompression. A test inspired by the Norsok M-710 / ISO 23936-2 test was conducted to assess the performance of Kalrez® OG193 which is specifically designed for RGD resistance.

The two main differences of this test compared to the formal ISO 23936-2 are the gas composition and the fixture type. The gas composition used in the test is 100% CO_2 instead of a mix of 10% CO_2 with 90% nitrogen. Higher CO_2 content is generally regarded as being more aggressive. Additionally, this test uses open groove fixture type with unlimited free volume instead of the standardized fixture specified by the ISO.

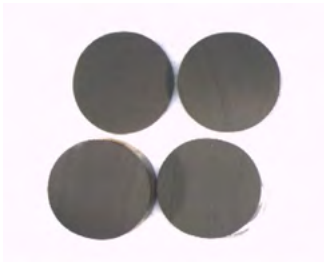
The pressure cycles are shown in the chart below:



Results of this test also show best RGD rating according to ISO 23936-2, without noticeable damages inside the cross section of the ring (rating 0000).

Kalrez® OG193 rating:

Pass: 0000



Pass: 0000

Vespel® solutions for CCUS

DuPont™ Vespel® parts and shapes are often used in compressor and pumping machinery, making them ideal solutions in the Capture and the Compression steps in CCUS. We offer a portfolio of product families for these applications.

1) The Vespel® CR Family

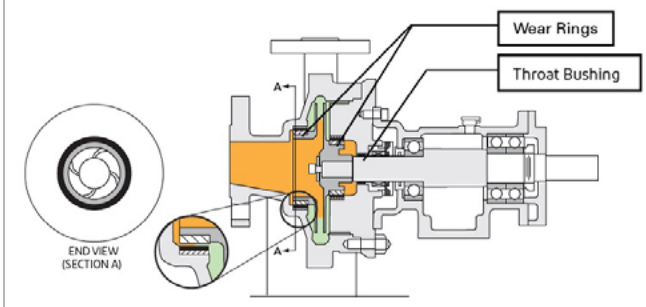
Vespel® CR family provides excellent chemical resistance in refineries or chemical processing. They offer high-creep resistance for seals, run-dry capability for wear rings for pumps and easy machinability for tight-tolerance parts like ball-valve seats.

DuPont™ Vespel® CR-6100 parts and shapes are composite materials consisting of carbon fibers held in a fluoropolymer resin matrix (PFA/CF Reinforced Composite, with random x-y oriented carbon-fiber).

DuPont™ Vespel® CR-6100 meets the following specification per API STD/ISO 13709, Centrifugal Pumps For Petroleum Petrochemical and Natural Gas Industries:

- -46 to 230 °C (-51 °F to 446 °F) temperature limits
- 2,000 kPa (20 bar; 300 psi) limiting pressure differential per wear part linear measure of 25 mm (1.0 inch)

Due to its low creep and high thermal resistance, Vespel® CR-6100 often excels where other chemically-resistant plastics fall short. This makes Vespel® CR-6100 particularly well suited for seals, wear rings and other components used in a variety of devices and operating conditions. Vespel® CR-6100 has been installed in thousands of pumps in refineries, chemical plants, power plants, and other fluid processing facilities since 1996. Properties of Vespel® CR-6100 help to reduce the risk of pump seizure and allow internal rotating-to-stationary part clearances to be reduced by 50% or more.



DuPont™ Vespel® CR-6100 for pump wear parts can help contribute to:

- Increased Process Uptime
- Reduced Cost of Maintenance
- Savings in Operation Cost

Function of wear rings for pump

Vespel® CR-6100 stationary wear rings

2) The Vespel® S Family

Vespel® S polyimide family of parts and shapes offers a diverse set of attributes. These products are highly durable and are used in demanding applications where exceptional thermal resistance, low wear and/or low friction, strength and impact resistance are desired.

SP-1

Unfilled. Superior wear and insulation properties with operating temperatures from cryogenic to 300 °C. Low electrical conductivity. Highest elongation and purity of SP family. Available as custom parts or stock shapes.

SP-21

Graphite-enhanced with low-friction properties for use with or without lubrication in various applications. Available as custom parts or stock shapes.

SCP-5050, SCP-5009 and SCP-50094

Higher thermal oxidative resistance than SP polyimides with superior chemical resistance. SCP-5050 matches the CTE of steel. SCP-5009 and SCP-50094 approximates the CTE of aluminum. Available as custom parts or stock shapes.

High pressure sealing and rapid gas decompression resistance of Vespel® S

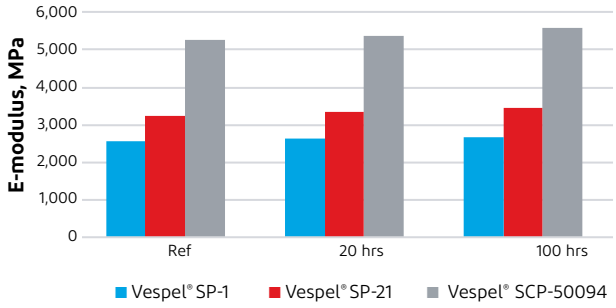
Vespel® polyimide was tested in ageing and RGD in supercritical CO_2 conditions to assess its performance at elevated temperature and pressure. The test conditions are described in the following table:

Test conditions	
Testing	Ageing and rapid gas decompression
Gas	100% CO_2
Temperature	150 °C / 302 °F
Pressure	200 bar / 2,900 psi
Decompression rate	120 bar/min – 1,740 psi/min
Duration	20 hours and 100 hours
Specimen	ISO 527-1BA
Vespel® polyimide grades	Vespel® SP-1 (unfilled polymer)
	Vespel® SP-21 (graphite filled PI)
	Vespel® SCP-50094 (advanced filler technology)
Tested properties	E-Modulus, elongation at break, visual inspection

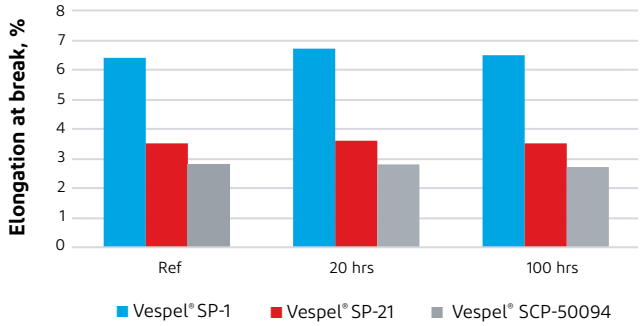
No visual defect or dimensional change was observed on the tensile specimens after 100 hours ageing coupled with a rapid gas decompression event.

No significant impact over the E-modulus or the elongation at break was noticed after testing.

Impact of RGD and sCO_2 over E-modulus



Impact of RGD and sCO_2 over elongation at break



Offering summary

Kalrez® Materials

This chart displays the recommended Kalrez® products for CCUS service with selected chemical resistance and mechanical properties.

Best Suitable Not suggested

Kalrez® Grades		6375	7275	6380	7090	7375	7390	0090	OG193
Hardness Shore A		75	75	80	90	79	89	95	94
Chemical resistance									
Carbon dioxide									
Hydrocarbons									
Solvents									
Water/Steam up to 200 °C (392 °F)									
Amines	DEA								
	MEA								
	DGA								
Ammonia									
Methanol									
Dry heat up to 200 °C									
Nitrogen oxide									
Mechanical properties									
High Pressure / Extrusion Resistance									
Long term sealing / CSR									
RGD Resistance									

According to the test made to assess amine resistance, compatibility with supercritical CO_2, and rapid gas decompression resistance, Kalrez® Parts could provide significant benefit in Carbon Capture Utilization and Storage specifically in various equipment such as:

- Capture with chemical or solvent absorption:
  - Absorber
  - Regenerator
  - Reboiler
  - Heat exchanger
  - Pumps, mechanical seal
- Compression and Transportation of CO_2
  - Compressors
  - High pressure CO_2 valves, pipe connectors and flanges
  - Transport tanks
- Sequestration & storage
  - CO_2 injection valve
  - Injection pipe seal

Vespel® Materials

The two main areas where Vespel® can be used are the capture and transport phase in CCUS. Vespel® CR is recommended for use in chemically aggressive service pumps and compressors. Vespel® S can be used for transport and storage components, such as valve seats, bushings, and seals.

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

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