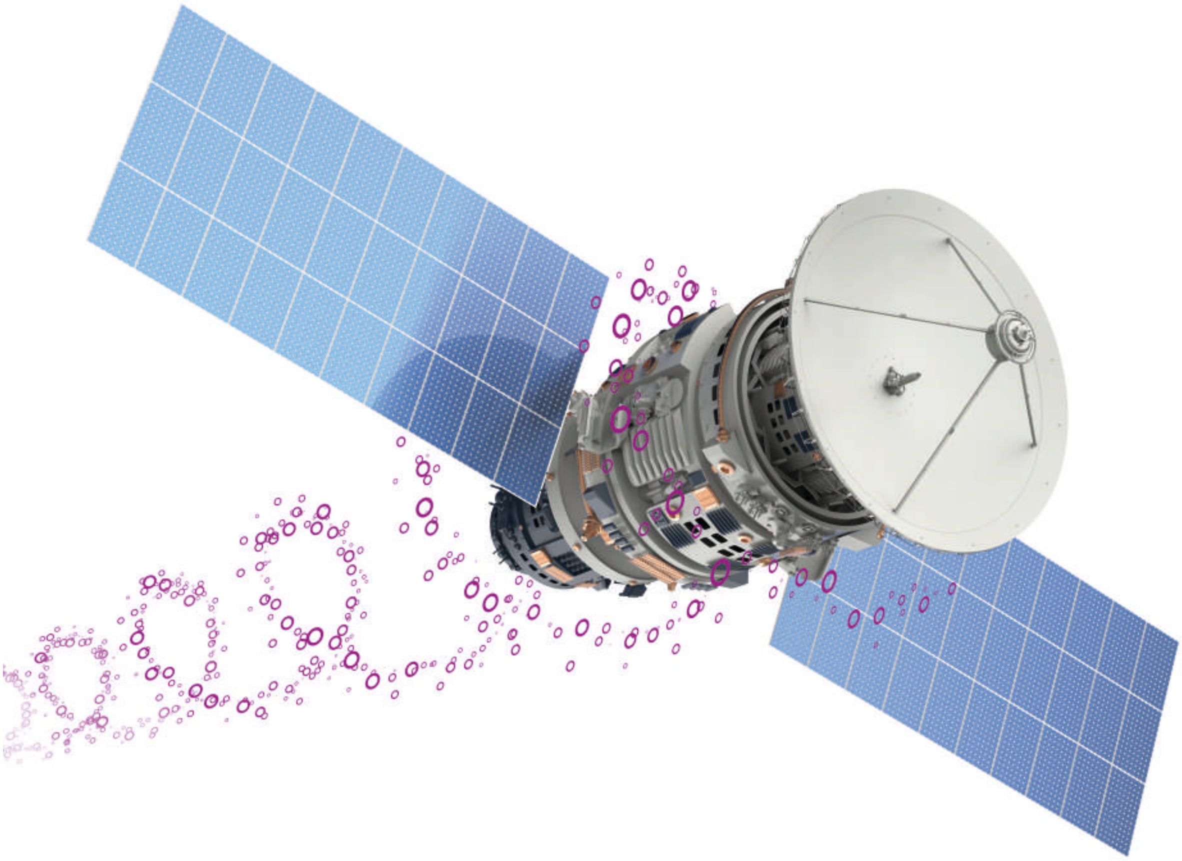
AEROSPACE APPLICATIONS

Powerful solutions for sustainable propulsion

PROPULSE®



EVONIK
Leading Beyond Chemistry

OUR MISSION – FUTURIZE PEROXIDE

Evonik is one of the world's leading producers of hydrogen peroxide and peracetic acid. The Active Oxygens business line has production facilities at 18 locations around the world. Its plants

CONTENTS

can be found in Europe, North America, South America, Africa, Asia, and Oceania, ensuring ready availability of hydrogen peroxide no matter where a customer is located. The company offers a wide variety of hydrogen peroxide and peracetic acid products tailored to specific applications, such as chemical synthesis, municipal and industrial wastewater treatment, food processing and safety, aseptic packaging, semiconductor manufacturing, aerospace applications, active pharmaceutical ingredients, cosmetics, and more.
Visit us at active-oxygens.com

MISSION? POSSIBLE!

More and more satellites are needed to serve the rapidly increasing demand for telecommunications and scientific data.

A NEW ERA OF AEROSPACE ENGINEERING IS DAWNING – AND WE PROVIDE THE FUEL FOR THE FUTURE. WE CAN LIFT YOUR BUSINESS INTO HIGHER ORBITS.

Gone are the days in which only superpowers were capable of sending rockets and satellites into space. At the dawn of a new space race private corporations across the globe are particpating in commercial space flight. One trend is clearly forging ahead towards large rockets capable of lifting heavyweight manned and unmanned payloads, whereas another trend supports small and flexible rockets. In the case of the latter, many startups are driving the development of small but powerful rockets capable of launching lightweight micro- and cube satellites into orbit.

Satellites are the smart outposts of a world that is getting more technologized and connected. They provide data for traffic monitoring, weather forecasts or even agriculture. Without satellites our life would be very different. We could not communicate across the globe or watch live international television broadcasts. Navigation systems couldn't help us to find our way anywhere in the world or get detailed weather information.

What the space sector is looking for are reliable and cost-effective rockets to carry the satellites into their position in orbit. At the same time, there is a demand for propellants, which are easy to use and have significantly reduced impact on the environment. That's where Evonik comes into the picture with its propulsion grade, PROPULSE®.

A PIONEER FOR GREEN ROCKETRY

Hydrogen peroxide manufactured by Evonik has been used as an oxider for operation of turbopumps in the fuel pumps of the Soyuz launch rocket for many years. Today, PROPULSE® is also used as direct fuel for smaller rockets. The powerful product is not just easy to handle and readily available, but also environmentally benign, making it a future-proof pioneer for green rocketry. Unlike other common fuels, it doesn't release toxic byproducts.

Numerous startups around the world are already using hydrogen peroxide as a green fuel in their latest rocket generations. When will you lift off with PROPULSE®?

PROPULSE® – OUR SYSTEM SOLUTIONS FOR THE AEROSPACE INDUSTRY

Evonik is a trusted long-term partner to the aerospace industry, supplying PROPULSE® products of superior quality and a technical service. PROPULSE® is more than hydrogen peroxide – namely a package of solutions forlaunchers, upper stages and sounding rockets providing additional value to our customers.

Evonik's success is first and foremost the success of our customers. Close communication is essential in understanding customers' needs and leads to providing the best and most solution-oriented support. We are always open minded when proposing solutions to our customers' most challenging needs.

- High specific impulse and high average density*
- Green propellant properties
- Global availability in industrial quantities
- Simple and safe handling*
- Experienced technical support

* Compared to other liquid oxidizers

Did you know?

- Peroxides are part of Evonik's DNA. In 1910 the first plant using the Weissenstein electrolysis process to produce H_2O_2 was put into operation.
- Evonik is a leading supplier of H_2O_2 with 18 production sites and an annual global capacity totaling more than one million metric tons.
- Thanks to a self-developed process, we are capable of manufacturing hydrogen peroxide solutions of up to 98 % that are of the highest purity and highest concentration.

Why is PROPULSE® a green propellant?

During its decomposition H_2O_2 does not release any substances, which could be harmful to humans or the environment. It decomposes into water and oxygen – nothing else.

"For launcher applications and space transportation to low orbit, the potential for hydrogen peroxide is large. It is the only real green alternative available today, which is affordable and technologically proven for decades. For our rockets, we trust in PROPULSE® from Evonik."

C.J. Onno Verberne
VP Business Development Space
Nammo Raufoss AS

IMPORTANT PHYSICAL PROPERTIES

Hydrogen peroxide is a colorless water-soluble liquid. Pure hydrogen peroxide is primarily of interest in scientific communities. Its aqueous solutions, however, are widely used in many industrial markets and in various applications – from personal care to rocket science!

The molecular structure as well as oxygen's oxidation state define the chemical properties of hydrogen peroxide. The oxygen atom, when in oxidation state I, allows hydrogen peroxide to participate in both oxidation as well as reduction reactions. Although hydrogen peroxide is well known as a strong oxidizing agent, its reduction properties play an important role in some applications. Typical chemical reactions, in which hydrogen peroxide is involved, are oxidation and reduction reactions, formation of other peroxygen or adduct compounds. Evonik supplies standard as well as high purity hydrogen peroxide, depending on the quality requirements of the particular application – like PROPULSE® for the aerospace industry.

Based on their high oxidation potential, hydrogen peroxide products are known to be strong oxidizing disinfectants and can be used for biocidal applications as well.

Properties of H_2O_2 in different concentrations

Parameter	Hydrogen peroxide solution						
H_2O_2 concentration (%, g/hg)	50	70	80	85	90	95	100
Density (g/cm³ @ 20°C)	1.20	1.29	1.34	1.37	1.39	1.42	1.45
Melting point (°C)	-52.0	-40.0	-25.0	-17.9	-12.0	-5.6	-0.4
Boiling point (°C)	114	126	133	137	141	145	150
Viscosity (mPa·s @ 20°C)	1.17	1.23	1.25	1.26	1.26	1.26	1.25
Adiabatic decompostion temperature (°C)	100	223	487	613	740	867	996
Evaporation of water due to decomposition heat (%)	65.5	100	100	100	100	100	100
Gas volume (L @ ADT per 1 kg solution)	1076	1974	2893	3331	3761	4179	4592
Oxygen volume (L @ ADT per 1 kg solution)	179	251	287	305	323	341	359

Environmental Impact

Due to hydrogen peroxide's unique chemical properties and environmental compatibility, it is a perfect candidate for extensive use in a variety of environmental applications. There are numerous examples where hydrogen peroxide helps to prevent or reduce negative impacts on the environment. Furthermore, hydrogen peroxide is often regarded as a true "green chemical". In contrast to many other red-ox agents, hydrogen peroxide decomposes into water and oxygen only, thereby not interfering with subsequent reaction steps.

H_2O_2: Unique fuel – Many Advantages

New space is ready for hydrogen peroxide. Its flexibility in application and environmentally benign nature allow the advancement of simple, cost-effective, and greener propulsion with sufficient performance to replace toxic propellants. The high specific impulse and high average density result in advantageous propellant performance for future generation of mono-, bipropellant, and hybrid rocket engines. A further benefit is the significant cost savings associated with the drastic simplification of the health and safety protection procedures necessary during propellant production, storage, and handling.

ROCKET PROPULSION SYSTEMS

THERE ARE THREE DIFFERENT FUNDAMENTAL TYPES OF ROCKET ENGINES AVAILABLE: MONOPROPELLANT, BIPROPELLANT AND HYBRID-PROPELLANT. THEY ALL CAN USE PROPULSE® AS A PROPELLANT.

MONOPROPELLANT SYSTEM

A monopropellant system uses a single substance that reacts or decomposes by itself to form hot gas, releasing energy as heat. This system is very simple, but only delivers medium performance. The most commonly used monopropellant system relies on hydrazine. However, hydrazine is a very toxic and flammable substance that represents a high risk for people working with it. In addition, its freezing point is around 1.5 °C, which can generate thermal problems during a spacecraft's mission. An alternative solution is to use hydrogen peroxide, which can be stored as liquid and has a high density level. The system consists of a tank and a thrust chamber. The pressure in the propellant tank forces the liquid into the injector. It enters as a spray into the thrust chamber and contacts a catalyst bed. The catalyst bed consists of a decomposition catalyst. The decomposing liquid produces heat, which further expands the gases. While monopropellant systems are quite simple to construct and control, they are limited in thrust. For higher thrust, the most preferred systems are based on liquid bipropellants.

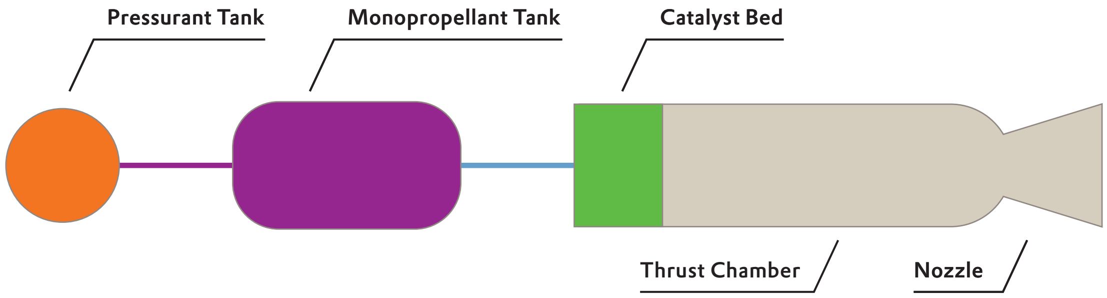
BIPROPELLANT SYSTEM

Bipropellant systems need a complex pumping system, pressure controls, valves and a feed system to deliver the propellants to the combustion chamber, all of which reduce the mass ratio and hence the efficiency of the system. The liquid propellant system with the highest energy density has a very low boiling point. Liquid hydrogen (LH_2) fuel, for example, has a boiling point of – 252 °C and an oxidizer, such as liquid oxygen (LOX), boils at – 183 °C. Using these high energy density propellants, in gaseous form, is impractical, since the enormous on-board storage tanks and pumping systems they require would be too big and heavy. Even in liquid form they are difficult to use, as the storage tanks need to be insulated and the pumps must work at very low temperatures with a very high temperature gradient across the body of the pump. Safety, handling and storage are also issues of concern. Nevertheless, cryogenic propellants are used when controllable, maximum thrust is a priority. Such a system consists of two separate tanks, pumps and a single combustion chamber. The pumps need to be operated carefully to achieve the best stochiometric mixture. The pumps need to be powered by a gas generator or an auxiliary engine and they need to be able to work at very low temperatures.

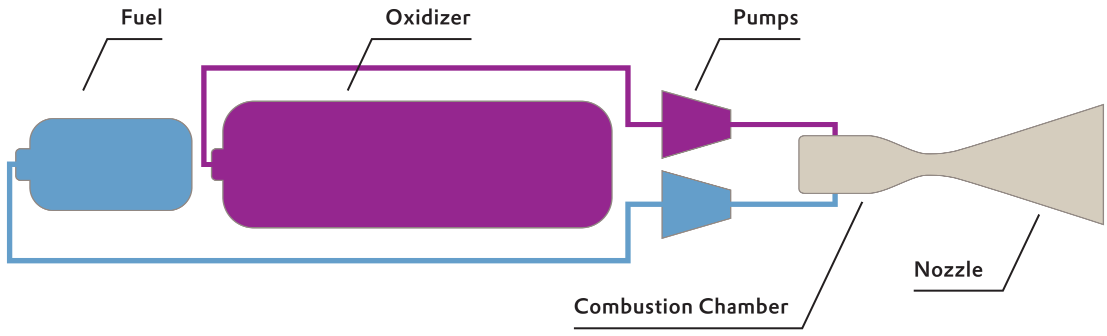
HYBRID PROPELLANT SYSTEM

A way simpler option than a bipropellant system is a hybrid-propellant rocket, a system that uses rocket propellants in two different phases: one solid and the other either a gas or a liquid. Hybrid rockets avoid some of the disadvantages of solid-fuel rockets like the dangers of propellant handling, while also avoiding some disadvantages of liquid rockets like their complexity.
In its simplest form a hybrid rocket consists of a tank containing the liquid oxidizer and a combustion chamber containing the solid fuel. When thrust is desired, the valve is opened, liquid propellant enters the combustion chamber, where it vaporizes and then reacts with the solid fuel. Hydrogen peroxide can be used as a liquid oxidizer in hybrid propulsion. Suitable solid fuels are hydroxyl terminated polybutadiene (HTPB) or simple polyethylene. These substances are easy to handle, and they don't pose a high risk for people working with them. When the substances react, only water and carbon dioxide are produced, making this combination a very good example of green rocketry. By using hydrogen peroxide combined with a catalyst chamber, a very reliable, reusable ignition system can be realized.

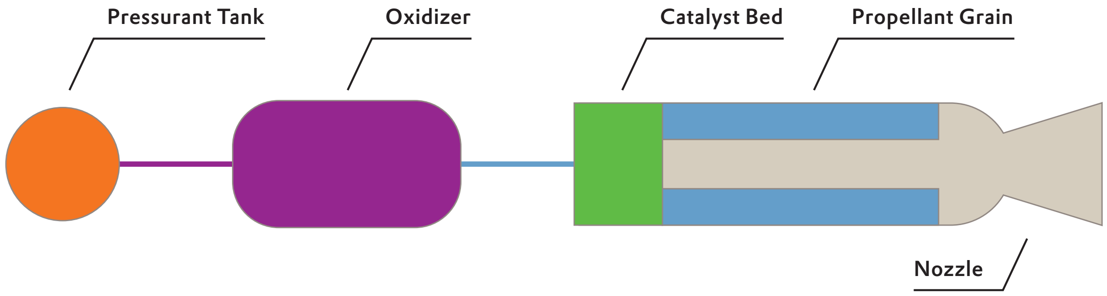
Monopropellant System



Bipropellant System

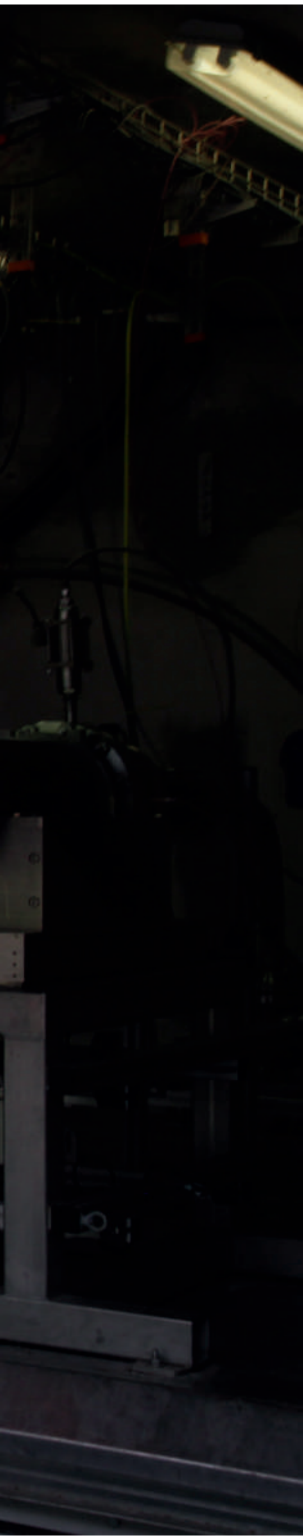


Hybrid Propellant System



The German Aerospace Center (Deutsche Zentrum für Luft- und Raumfahrt, DLR) successfully tests the VISERION hybrid rocket engine using Evonik's highly concentrated hydrogen peroxide, PROPULSE®.

(Photo credit: DLR, CC BY-NC-ND 3.0)



GERMAN AEROSPACE CENTER DLR RATES THE USE OF HYDROGEN PEROXIDE FOR THE AEROSPACE INDUSTRY

The German Aerospace Center (DLR) is Germany's national aerospace and space research center. DLR's mission comprises the exploration of the Earth and the Solar System and research into protecting the environment. This includes the development of environment-friendly technologies for energy supply and future mobility, as well as for communication and security.

The Institute of Aerodynamics and Flow Technology of the DLR is developing AHRES (Advanced Hybrid Rocket Engine Simulation). AHRES is a software tool for the pre-design of hybrid rocket engines, irrespective of thrust class. In addition, the pre-design of solid rocket engines as well as monopropellant thrusters based on hydrogen peroxide is possible. For the validation of this software, the Spacecraft Department is operating several hybrid rocket engines up to 15 kN thrust.

Therefore, an in-house test rig for hybrid rocket engines and monopropellant thrusters is in operation at the DLR test site in Trauen. The engines are propelled with polymeric solid fuels based on POLYVEST HT-A (HTPB) and PROPULSE® as the liquid oxidizer. The decision to use this propellant combination is based on an extensive examination. The goal was to find an efficient and environmentally friendly composition, which creates a compact rocket system with thrust that is controllable over a wide range.

To achieve the optimum composition, the properties of different liquid oxidizers were compared, as listed in the table on the following page, where the benefits for using hydrogen peroxide are outlined. The theoretical performance values (mass and volume specific impulse as well as combustion temperature) over the oxidizer-to-fuelratio are shown in Figures 1 to 3.

DLR

H_2O_2 Advantages for Space Propulsion Applications

- **High volume specific impulse**
  for smaller, more compact rockets due to higher propellant density.

- **High O/F ratio**
  sallows smaller combustion chambers due to lower fuel requirement. This will reduce problems, which occur in hybrid rocket engines, due to the increasing flow crosssection and fuel block geometry.

- **Flat ISP curve**
  enables engine control over a large thrust range with relatively low loss of efficiency.

- **Lower combustion chamber temperatures**
  significantly reduced thermal loads for the construction and heat-shielding materials, which enables a lower engine dry mass.

- **Controlled shelf life**
  allows storage in suitable facilities with low energy consumption. If the tank construction is suitable, the oxidizer can remain in the engine tank over long periods of time.

- **Low toxicity and noncryogenicity**
  low health risks during handling, particularly long-term impact and cumulative effects are very low. Environmental hazards are excluded due to self-induced degradation to climate-neutral water and oxygen.

- **Catalytically decomposable**
  allows the construction of reliable, reigniteable start systems. Excludes hazards due to ignition delay.

Table 1: Comparison of different liquid oxidizers for hybrid rocket engines

	H_2O_2	N_2O	N_2O_4	HNO_3	LOX
Maximum specific impulse	mid to high	mid	high	mid	very high
Density	high	low	high	high	mid
Maximum volume specific impulse	mid to high	low	high	high	mid
Optimum O/F ratio	high	high	mid	mid	low
Isp curve	flat	flat	rather steep	rather steep	steep
Storability	storable under controlled atmosphere	storable under pressure	storable under controlled atmosphere	storable, highly corrosive	cryogenic
Environment and handling	• nontoxic • noncarcinogenic • corrosive • oxidizing	• nontoxic • noncarcinogenic • noncorrosive • oxidizing	• toxic • potentially carcinogenic • corrosive • oxidizing	• toxic • noncarcinogenic • corrosive • oxidizing	• nontoxic • noncarcinogenic • noncorrosive • oxidizing • cryogenic

SOURCE: *Stefan May, German Aerospace Center, Institute of Aerodynamics and Flow Technology, Department Spacecraft. Data are generated with the NASA CEA-Code*

Comparison of theoretical performance values over the oxidizer-to-fuel-ratio

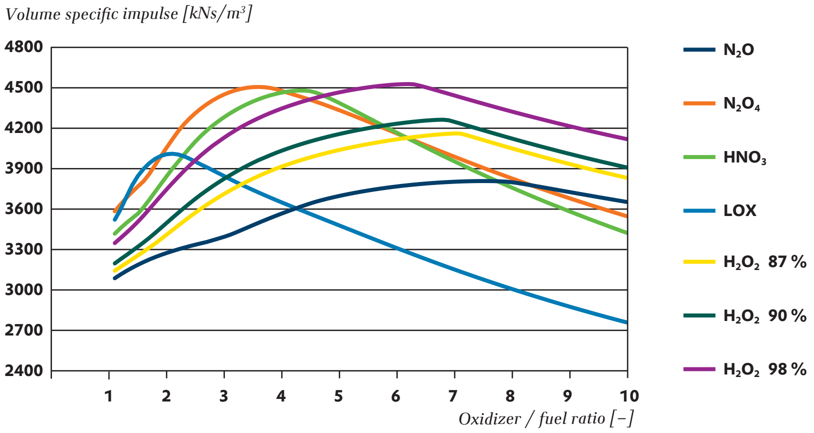


Figure 1: Theoretical volume specific impulse for different oxidizers over the oxidizer-to-fuel-ratio (fuel: 87 % HTPB + 13 % Al; pressure 70 bar; expansion ratio 100)

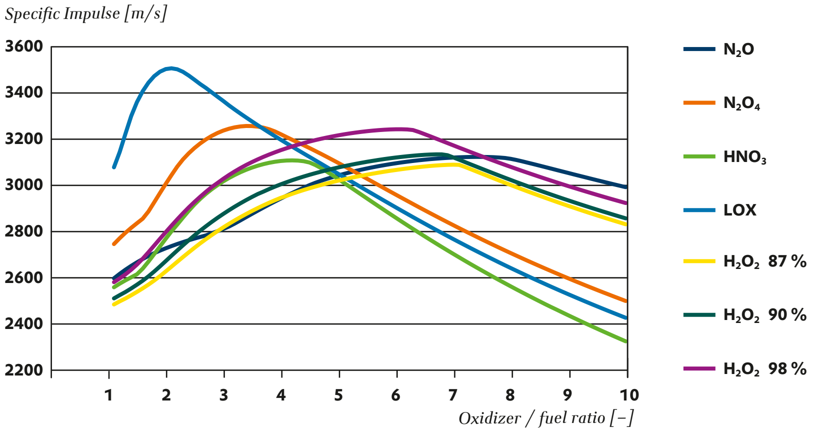


Figure 2: Theoretical mass specific impulse for different oxidizers over the oxidizer-to-fuel-ratio (fuel: 87 % HTPB + 13 % Al; pressure 70 bar; expansion ratio 100)

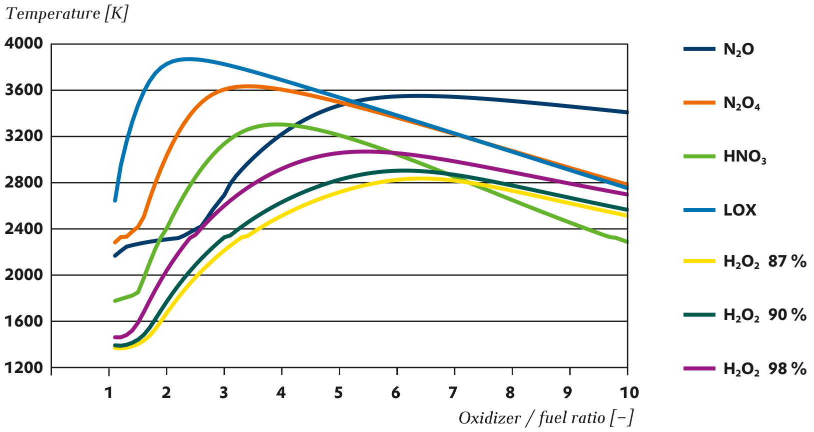


Figure 3: Theoretical combustion temperature for different oxidizers over the oxidizer-to-fuel-ratio (fuel: 87 % HTPB + 13 % Al; pressure 70 bar; expansion ratio 100)

***SOURCE:** Stefan May, German Aerospace Center, Institute of Aerodynamics and Flow Technology, Department Spacecraft. Data are generated with the NASA CEA-Code*

PROPULSE® – GRADES AND PACKAGING

GRADES

Evonik has a long track record in the production of high test peroxide grades specifically designed for aerospace applications. These products are marketed under the trademark PROPULSE® and supplied to customers globally.

PROPULSE® grades are available in different concentrations ranging from 82.5 % and up to 98 % hydrogen peroxide. All our grades have a purity of 99.99 %.

TRANSPORT PACKAGING

Depending on the customer, grade, region and additional requirements, shipments of PROPULSE® can be delivered in a variety of small to large packagings. For consumers of larger quantities, the installation of a storage tank is recommended.

1.25 and 12.5 L aluminium containers
Samples or smaller quantities of PROPULSE® are shipped in 1.25 or 12.5 L pure aluminium bottles. Packed in the

original bottles and stored under moderate temperatures (10 – 20 °C) and dry conditions, extended storage periods without significant loss of activity can be achieved.

Aluminium containers
For medium sized orders (up to 2000 kg) we have specially designed transport containers, which are covered by German Utility Model Protection ("Gebrauchsmusterschutz"). These are reusable transport containers made of pure aluminum with a maximum fill volume of 220 L.

ISO tank containers

- The ISO tank containers with a maximum fill volume of approx. 19 m^3 are made of stainless steel. The inner surface of the containers is especially treated in order to transport PROPULSE® without any quality deterioration.
- When receiving PROPULSE® in ISO tanks, our advice is to unload PROPULSE® into dedicated storage tanks made of pure aluminium shortly after delivery. This is to assure the stability and quality of PROPULSE® prior to its use.
- If there is a risk of PROPULSE® being exposed to elevated temperatures for extended periods of time during transport, ISO containers with a cooling system can be deployed.

BOTTLES
1.25 L PURE ALUMINUM
12.5 L PURE ALUMINUM

CONTAINER
250 KG PURE ALUMINUM

BULK CONTAINER
20' ISO TANK CONTAINER THERMO
20' ISO TANK CONTAINER STANDARD

PROPULSE®

STORAGE

Hydrogen peroxide in containers should be stored in roofed, fireproof rooms to keep them cool and protected from sunlight. It is important that the hydrogen peroxide is protected against all types of contamination.

The containers should be stored unopened and in an upright position without blocking the breather vents. With proper storage in the original containers or in tank installations, the product can be stored safely for long periods of time without noticeable losses in concentration (typical shelf life of one year).

When handling large volumes of hydrogen peroxide it is suggested that the product be stored in large tank installations. Due to the properties of the products, a range of safety aspects need to be observed when constructing a bulk storage plant and dosage units. Our engineering service team can assist you with various aspects of bulk storage, including tank construction planning and engineering, manufacturing and installation, installation startup, safety.

Please contact us regarding your product requirements. Email: active.oxygens@evonik.com

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At Evonik Active Oxygens, **sustainability** is at the core of futurizing our business. We make some the world's greenest chemicals: After their powerful oxidation action, hydrogen peroxide and peracetic acid break down into benign substances that leave no trace of harmful chemicals on food or the environment. Learn more about how green rocketry contributes to sustainable space activities:
https://active-oxygens-sustainability.evonik.com/en/stories

EVONIK
Leading Beyond Chemistry