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# Cryogenic Technology & Rocket Engines

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## ABSTRACT
This paper is all about the rocket engine involving the use of cryogenic technology at a cryogenic temperature (123K). This basically uses the liquid oxygen and liquid hydrogen as an oxidizer and fuel, which are very clean and non-pollutant fuels compared to other hydrocarbon fuels like petrol, diesel, gasoline, LPG, CNG, etc., sometimes, liquid nitrogen is also used as an fuel.

## Keywords
Rocket engine, Cryogenic technology, Cryogenic temperature, Liquid hydrogen and Oxygen.

## 1. INTRODUCTION
Cryogenics is the study of production of very low temperature nearly about "123K“" in which the material's behavior and properties are studied at that temperature.

## 2. HISTORY OF CRYOGENIC ROCKET ENGINE
In 1963, United States of America was the first country to develop the CRE with the use of RL 10 engines with the successful flight and it is still used on Atlas-V rocket. Other countries are like: Japan used LE5 in 1997, France used HM7 in 1979 used the respective rocket engines. Here the mixture of liquid N2, H2 and O2 are used as fuels. In 1987, first CRE was launched with human in space.

## 3. CONSTRUCTION & WORKING OF CRYOGENIC ROCKET ENGINE

### 3.1 What is Cryogenics?
Kryo = very cold
Genics= to produce

- Cryogenic is the science & technology associated with generation of low temperature below 123 k (-150 deg Celsius)
- Cryogenic Engines
  - ➢ These are powered by the cryogenic propulsion.
  - ➢ Liquid hydrogen is used as a fuel to propel the rocket.
  - ➢ Liquid oxygen (O2) is used as an oxidizer..

### 3.2 What is Cryogenic Rocket Engine?
- A cryogenic rocket engine is a rocket engine that uses a cryogenic fuel or oxidizer, that is, its fuel or oxidizer (or both) is gases liquefied and stored at very low temperatures. Notably, these engines were one of the main factors of the ultimate success in reaching the Moon by the Saturn V rocket.
- During World War II, when powerful rocket engines were first considered by the German, American and Soviet engineers independently, all discovered that rocket engines need high mass flow rate of both oxidizer and fuel to generate a sufficient thrust. At that time oxygen and low molecular weight hydrocarbons were used as oxidizer and fuel pair. At room temperature and pressure, both are in gaseous state. Hypothetically, if propellants had been stored as pressurized gases, the size and mass of fuel tanks themselves would severely decrease rocket efficiency. Therefore, to get the required mass flow rate, the only option was to cool the propellants down to cryogenic temperatures (below −150 °C, −238 °F), converting them to liquid form. Hence, all cryogenic rocket engines are also, by definition, either liquid-propellant rocket engines or hybrid rocket engines.
- Various cryogenic fuel-oxidizer combinations have been tried, but the combination of liquid hydrogen (LH2) fuel and the liquid oxygen (LOX) oxidizer is one of the most widely used. Both components are easily and cheaply available, and when burned have one of the highest entropy releases by combustion, producing specific impulse up to 450 s (effective exhaust velocity 4.4 km/s).

### 3.3 Components
The major components of a cryogenic rocket engine are: combustion chamber (thrust chamber), pyrotechnic igniter, fuel injector, fuel cryopumps, oxidizer cryopumps, gas turbine, cryo valves, regulators, the fuel tanks, and rocket engine nozzle. In terms of feeding propellants to combustion chamber, cryogenic rocket engines (or, generally, all liquid-propellant engines) work in either an expander cycle, a gas-generator cycle, a staged combustion cycle, or the simplest pressure-fed cycle.
The cryopumps are always turbopumps powered by a flow of fuel through gas turbines. Looking at this aspect, engines can be differentiated into a main flow or a bypass flow

configuration. In the main flow design, all the pumped fuel is fed through the gas turbines, and in the end injected to the combustion chamber. In the bypass configuration, the fuel flow is split; the main part goes directly to the combustion chamber to generate thrust, while only a small amount of the fuel goes to the turbine.

## 3.4 Characteristic Temperature of Cryogenic fluids

| Cryogen | Triple Point | Normal B.P. | Critical Point |
|---|---|---|---|
| Methane (CH4) | 90.7 | 111.6 | 190.5 |
| Oxygen (O2) | 54.4 | 90.2 | 154.6 |
| Argon | 83.3 | 87.3 | 150.9 |
| Nitrogen | 63.1 | 77.3 | 126.2 |
| Neon | 24.6 | 27.1 | 44.4 |
| Hydrogen (H2) | 13.8 | 20.4 | 33.2 |
| Helium | 2.2 | 4.2 | 5.2 |

It is however with the advent of Boltzmann’s statistical thermodynamics in the late 19th century that temperature until then a phenomenological quantity could be explained in the terms of micro structure dynamics.

Consider a thermodynamic system in a macro state which can be obtained by a multiplicity W of microstates. The entropy of system was postulated by Boltzmann,

$S= k_B \ln W$

¥ $k_{B} = 1.38 \times 10^{-23}$ S/K

Adding reversibility, heat ( d ө ) to the system produces a change of its entropy ( dS) , with a proportionality factor ‘T’ which is pre critical temperature:

T = dq/dS

Boltzmann also found that the average thermal energy of a particle in a system in equilibrium at temperature T is $E \sim k_B T$.

Consequently, a temperature of 1k is equivalent to thermal energy of $10^{-4}$ eV or $10^{-23}$ J/particle.

## 3.5 Cryogenic Fuels/Propellents

In a cryogenic propellant, the fuel and the oxidizer are in the form of very cold, liquefied gases. These liquefied gases are referred to as super cooled as they stay in liquid form even though they are at a temperature lower than the freezing point. Thus we can say that super cooled gases used as liquid fuels are called cryogenic fuels.

These propellants are gases at normal atmospheric conditions. But to store these propellants aboard a rocket is a very difficult task as they have very low densities. Hence extremely huge tanks will be required to store the propellants. Thus by cooling and compressing them into liquids, we can vastly increase their density and make it possible to store them in large quantities in smaller tanks. Normally the propellant combination used is that of liquid oxygen and liquid hydrogen, Liquid oxygen being the oxidizer and liquid hydrogen being the fuel. Liquid oxygen boils at 297 degree F

| Propellent | Liquid Hydrogen (Fuel) | Liquid Oxygen (Oxidizer) |
|---|---|---|
| Density (kg/m$^3$) | 70.8 | 1141 |
| Boiling point at atmospheric pressure (K) | 20.2 | 90.2 |

and liquid hydrogen boils at 423 degree F.

## 3.6 Working

Cryogenic Engines are rocket motors designed for liquid fuels that have to be held at very low "cryogenic" temperatures to be liquid - they would otherwise be gas at normal temperatures. Typically Hydrogen and Oxygen are used which need to be held below 20°K (-423°F) and 90°K (-297°F) to remain liquid.

The engine components are also cooled so the fuel doesn't boil to a gas in the lines that feed the engine. The thrust comes from the rapid expansion from liquid to gas with the gas emerging from the motor at very high speed. The energy needed to heat the fuels comes from burning them, once they are gasses. Cryogenic engines are the highest performing rocket motors. One disadvantage is that the fuel tanks tend to be bulky and require heavy insulation to store the propellant. Their high fuel efficiency, however, outweighs this disadvantage.

The Space Shuttle's main engines used for liftoff are cryogenic engines. The Shuttle's smaller thrusters for orbital maneuvering use non-cryogenic hypergolic fuels, which are compact and are stored at warm temperatures. Currently, only the United States, Russia, China, France, Japan and India have mastered cryogenic rocket technology.

The cryogenic engine gets its name from the extremely cold temperature at which liquid nitrogen is stored. Air moving around the vehicle is used to heat liquid nitrogen to a boil. Once it boils, it turns to gas in the same way that heated water forms steam in a steam engine. A rocket like the Ariane 5 uses oxygen and hydrogen, both stored as a cryogenic liquid, to produce its power. The liquid nitrogen, stored at -320 degrees Fahrenheit, is vaporized by the heat exchanger. Nitrogen gas formed in the heat exchanger expands to about 700 times the volume of its liquid form. This highly pressurized gas is then fed to the expander, where the force of the nitrogen gas is converted into mechanical power.

# 4. APPLICATIONS OF CRYOGENIC ENGINES

- Cryo pumps & turbo molecular pumps are required in space as the level of vacuum required in space simulation chambers are very high.
- Life of tools, die castings & their dies, forgings , jigs & fixtures increase when subjected to cryogenic

heat treatment.

- Cryogenic recycling-turns the scrap in raw material by subjecting it to cryogenic i.e. extremely low temperatures. This is mostly used for PVC, Rubber.
- Cryo-surgery is a novel technique in which the harmful tissues are destroyed by freezing them to cryogeni c temperature. It has shorter recovery time.
- Preserving food at low temperature is a well-known technique.

# 5. ADVANTAGES

Storable liquid stages of PSLV and GSLV engines used presently release harmful products to the environment.

The trend worldwide is to change over to eco-friendly propellants. Liquid engines working with cryogenic propellants (liquid oxygen and liquid hydrogen) and semi cryogenic engines using liquid oxygen and kerosene are considered relatively environment friendly, non-toxic and non corrosive. In addition, the propellants for semi-cryogenic engine are safer to handle & store. It will also reduce the cost of launch operations.

This advanced propulsion technology is now available only with Russia and USA. India capability to meet existing mission requirements. The semi cryogenic engine will facilitate applications for future space missions such as the Reusable Launch Vehicle, Unified Launch Vehicle and vehicle for interplanetary missions.

- High Specific Impulse
- Non-toxic and non-corrosive propellants
- Non-hypergolic, improved ground safety

# 6. DISADVANTAGES

- Low density of liquid Hydrogen –more structural mass
- Low temperature of propellants -Complex storage
- Transfer systems and operations
- Hazards related to cryogens
- Overall cost of propellants relatively high
- Need for ignition system

## *6.1 Drawback of Cryogenic propellants*

- Highly reactive gases

  Cryogens are highly concentrated gases and have a very high reactivity. Liquid oxygen, which is used as an oxidizer, combines with most of the organic materials to form explosive compounds. So lots of care must be taken to ensure safety.
- Leakage

  One of the most major concerns is leakage. At cryogenic temperatures, which are roughly below 150 degrees Kelvin or equivalently (-190) degrees Fahrenheit, the seals of the container used for storing the propellants lose the ability to maintain a seal properly. Hydrogen, being the smallest element, has a tendency to leak past seals or materials.

Hydrogen can burst into flames whenever its concentration is approximately 4% to 96%. It is hence necessary to ensure that hydrogen leak rate is minimal and does not present a hazard. Also there must be some way of determining the rates of leakage and checking whether a fire hazard exists or not. The compartments where hydrogen gas may exist in case of a leak must be made safe, so that the hydrogen buildup does not cause a hazardous condition.

# 7. CONCLUSION

This brief paper has presented the basic ideas and principles of the most important aspects of cryogenics i. e. cryogenics fluids and its application in developing cryogenic rocket engines.

The thrust produced in rocket engine is outwards and that in the jet engine is inwards. Hence, the efficiency of the cryogenic rocket engine is greater than the jet engine and it is very much economical by the use of liquid hydrogen and oxygen.

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