A Review Paper on the History and the Construction of Cryogenic Engine

Himanshu Shivcharan Bhandare
Raisoni, India

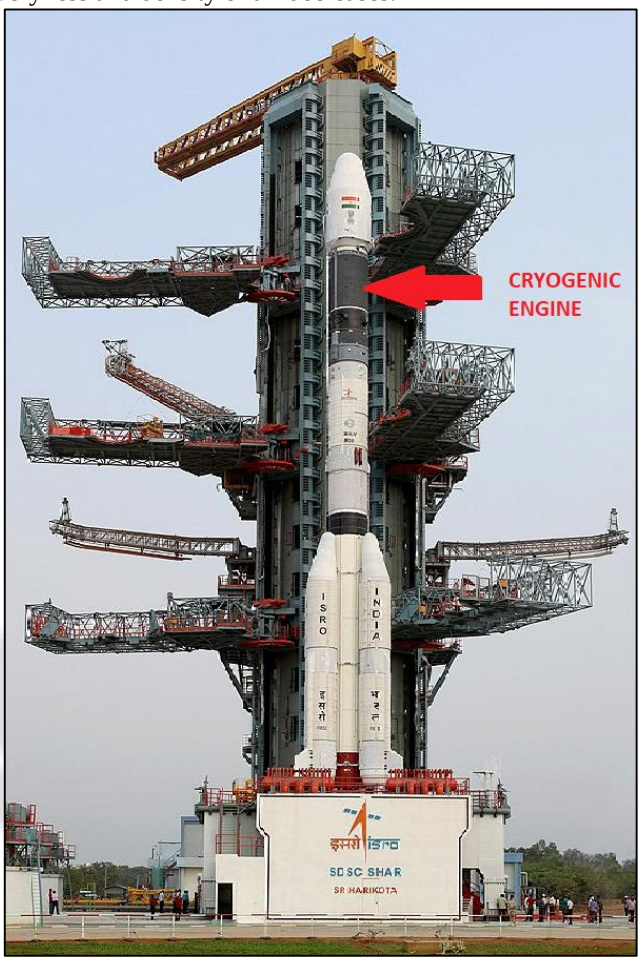
Abstract— Cryogenic is technology that every country wanted but due to its complex working and difficulty of handling of liquid propellant and oxidizer make it hard to develop. Only few countries have achieve and master this technology. Cryogenic engine follows the newtons third law of motion i.e; there is always equal and opposite reaction. Cryogenic engines have more efficiency than solid and liquid propellant. Every engine work only when it losses its heat but the whole concept of this engine is to loss heat and get output in the form of thrust. Nominal thrust of cryogenic engine is about 196.5 KN in vacuum with the specific impulse of 434 sec. All the cryogenic engine available follow some cycle for the operation basically there are four cycles which have discovered. Every engine have the basic component only difference in those engine are the flow of the fuel and the oxidizer in the engine. This technology is important because of that MTCR (Missile Technology Control Regime) restrict the use of cryogenic engine for missile manufacturing.

Key words: Liquid Propellant and Oxidizer, Newtons 3rd Law of Motion, Cryogenic Temperature, Rocket Engine

I. INTRODUCTION

Originally cryogenic word was originated from Greek word "kryo" which means cold or freezing ,"gene" which means burn or produce. the word cryogenic was use in the engines because the fuel we use in it is below zero degree celcious it is only engine that need temperature lower than room temperature . to achieve sub zero temperature of the gases we use cascade liquification of gas. This technology is hard because of the temperature of gas. it became very tricky to control and maintain the temperature of liquid oxygen and hydrogen. Even tiny leakage in the tank of the propellant and oxidizer can cause the engine failure. we use liquid oxygen as an oxidizer and liquid hydrogen as a propellant in some case we use liquid nitrogen as a propellant. in this engine liquid hydrogen is kept at -252.87^{0}C and liquid oxygen is at -218.79^{0}C and this is achieve by LINDE HAMPSON cycle with the help of heat exchanger, compressor, expansion valve and separator we can liquefy every gas. Plant of liquification is set up several kilometer away from the launch pad and when required it is filed in the tank of engine by pipes. few hours before launch we start to fill propellant and oxidizer in the engine fuel tank because every gas which is at liquid state is unstable and making it hard to handle. There is a replacement for the liquid hydrogen in rocket engines i.e; RP-1 (Refined Petroleum) this has low specific impulse time than liquid hydrogen but yet it is cheaper and also stable at room temperature. A cryogenic engine provides more force with each kilogram of cryogenic propellant it uses compared to other propellants, such as solid and liquid propellant rocket engines and its more efficient.

The cryogenic engine is generally below the actual satellite and work for maximum amount of time than rest of stage. it burn about 2.5 ton of fuel and oxidizer giving the thrust of 1.43 ton and last up-to 420 sec . cryogenic engine is only design to work in the vacuum because this engine use oxygen which is in the form of liquid. cryogenic engine start to burn at an altitude of 800KM from where oxygen become very less and density of air decreases.



II. HISTORY OF CRYOGENIC

A. First country to develop the cryogenic engine was USA.

They develop their engine back in 1963. The name of this engine was RL-10 which is about 4 meter in length, 2.15 meter in diameter and 301 KG without propellant . The main designer of hat engine was pratt & Whitney. After that many other countries start to develop the engine. In 1977 JAPAN develop their first engine in LE-5 and they follow the gas generator cycle following to this country FRANCE also master the technology by building FRANCE'S first cryogenic engine HM-7. Russia get their engine in 1983 in the form of KVD-1 and which follows the stage combustion. China approved their project in 2002 and after one year they build their prototype.

NATION	ENGINE/ROCKET USED	YEAR	CYCLE
USA	RL-10	1963	Expander
JAPAN	LE-5	1977	Gas-Generator

FRANCE	HM 7	1979	Gas-Generator
RUSSIA	KVD-1	1983	Staged combustion
CHINA	YF-77	2003	Gas-Generator
INDIA	CE-7.5	2013	Staged combustion

B. INDIAN HISTARY OF CRYOGENIC ENGINE

India started its program to develop cryogenic engine back in 90's. India have to develop cryogenic engine by their own because Russia did not help them. under Mikhail Gorbachev and Glavkosmos , the Soviet Union space agency, had agreed to transfer cryogenic engines and technology to ISRO. But very few countries have access to cryogenic engines and those who do, guard it zealously. The US, EUROPE, JAPAN and CHINA are averse to sharing. The Russians of course made an exception for INDIA. INDIA and USSR said cryogenic technology was strictly for non military uses. They would only be used for communication and weather satellite. The US did not belive them. In 1991 , the Bush (senior) administration invoke the Missile Technology Control Regime (MTCR), an association to stop proliferation of missile that could be used for mass destruction , to impose sanction on Soviet and Indian space agencies. soon after, the soviet union disintegrated and the a new government under Boris Yeltsin took control. Yeltsin's government fevered the West. In 1993 Yeltsin arrived at a compromise after he met Bill Clinton (who had taken over from Bush in January 1993) in the US. Russia would not transfer the technology, but it would sell seven cryogenic engines to India.

C. India decided to fight back

By developing its own cryogenic technology. Over the last 17 year, Indian scientists, most of them at ISRO's liquid propulsion center in Thiruvanthapuram worked on what was termed CUSP, cryogenic upper stage project. "cryogenic technology is not just about the engine. Each stage is like a rocket by itself" says an ISRO official.

III. CYCLE OF CRYOGENIC ENGINE

All the Cryogenic engine follows some cycle according to their requirement. Those cycles are different from each other by mixing of the fuel and the oxidizer. Developers choose different cycles according to the payload and how long engine should run. There are basically FOUR type of cycle in cryogenic engine those are as follows,

a) Expander
b) Gas-generator
c) Staged combustion
d) Combustion tap-off

A. Expander

The expander cycle is a power cycle of a bipropellant rocket engine. The expander rocket engine follows closed cycle. Heat from nozzle and combustion chamber powers the fuel and oxidizer. In this cycle, the fuel is used to cool the engines combustion chamber, picking up heat and changing phase. The heated, now gaseous, fuel then powers the turbine that drives the engines fuel and oxidizer pumps before being injected into the combustion chamber and burned.

Usage of Expander cycle i various engines which are as follows

- LE-5
- LE-9
- RL-10
- YF-7

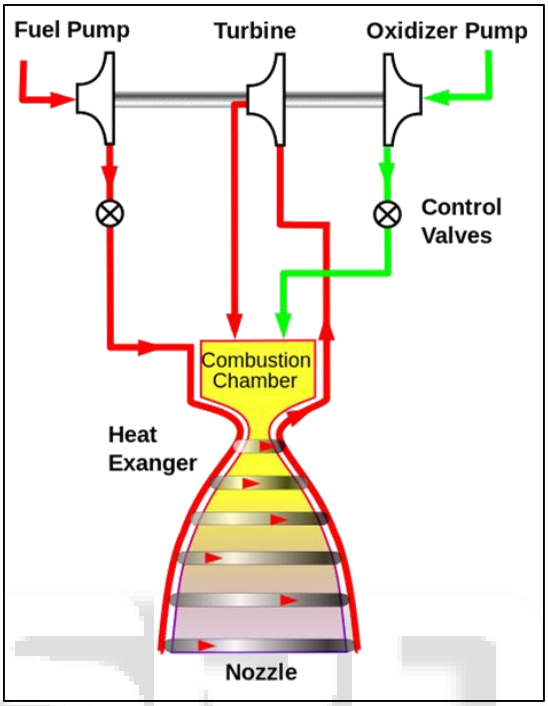


Fig. 1: expander

B. Gas-Generator

In this cycle some of the fuel and oxidizer is burned separately in the pre-burner to power the pumps and then send remaining in the combustion chamber for the combustion. most of gas-generator engines use the fuel for nozzle cooling. There are several advantage of gas-generator, it dose not need to deal with the counter pressure of injection the exhaust into the combustion chamber. This simplifies plumbing and turbine design, and results in a less expansive and lighter engine. The main disadvantage of this cycle is that it losses due to discarded propellant.

The usage of this cycle is in following rockets

- RS-68
- F-1
- CE-20
- RD-107

Rocket launch systems that use gas-generator combustion engines

- Falcon 9, Falcon Heavy
- Soyuz (RUSSIA)
- Saturn

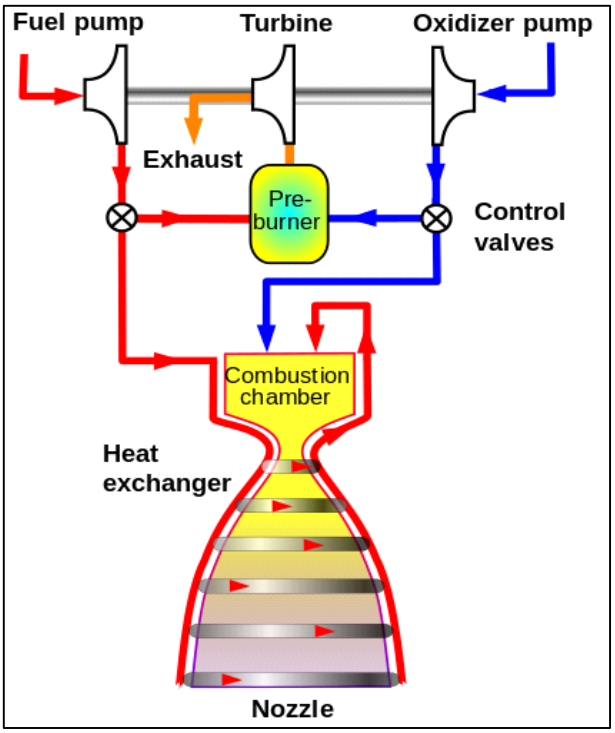


Fig. 2: gas-generator

C. *Staged Combustion*

The staged combustion cycle is sometimes known as topping cycle or pre-burner cycle. In this all of the fuel and a portion of the oxidizer are fed through the pre-burner, generating fuel-rich gas. After being run through a turbine to power the pumps, the gas is injected into the combustion chamber and burn with the remaining oxidizer. The fuel efficiency of the staged combustion cycle is in part of all propellant ultimately flowing to the main combustion chamber, contributing to thrust. The staged combustion cycle is sometimes called as closed cycle.

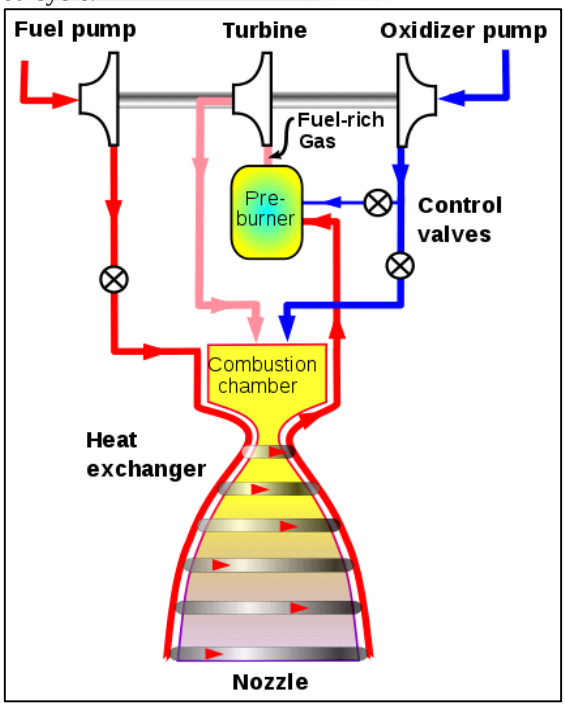


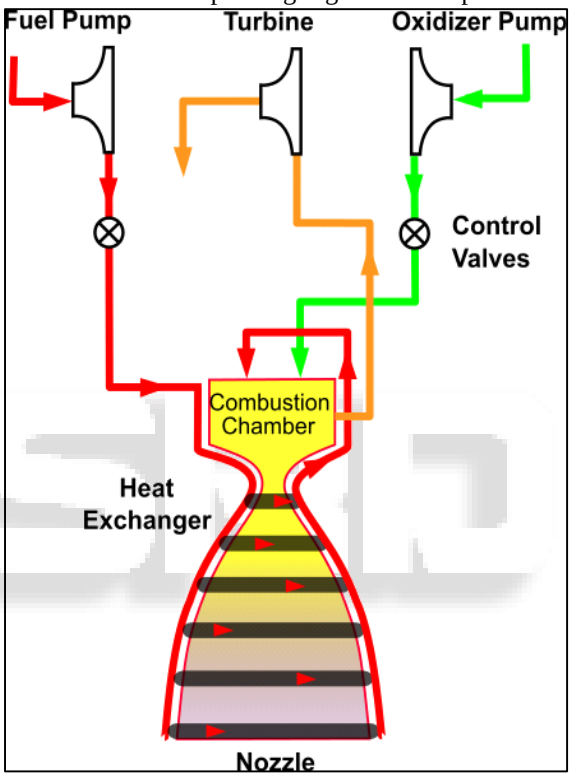
Fig. 3: Staged combustion

List of rockets which uses the Staged-combustion cycle;

- Space Shuttle
- GSLV
- Long March 5

D. *Combustion Tap-Off*

A small portion of exhaust from the combustion chamber is tapped off to power the turbines. The cycle routes hot gases from the main combustion chamber of the rocket engine and routes them through engine turbopump turbines to pump fuel, then is exhausted. Since not all fuel flows through the throat into the nozzle, the tap-off cycle is considered an open-cycle engine. The cycle is comparable to a gas-generator cycle engine with turbines driven by main combustion chamber exhaust rather than a separate gas generator or pre-burner.



IV. MAIN COMPONENTES IN CRYOGENIC ENGINE

A. *Gas Generator*

The Gas Generator is used to drive the turbo by a gas flow. The gas generated procedure this energy by pre-burning some amount of liquid fuel. use of gas generator with help of turbo pump increases the efficiency of this engine. The gas generator is place where the pipe of fuel passes which will rotate the turbine and run the pumps.

B. *Turbo Pumps*

The working of these pumps is simple and is run by the shaft which come from the gas generator. Turbo pumps rotate about 15000 rpm and this is minimum revolution required for to force fuel into the combustion chamber. These pumps are specially manufacture because we have to deal with fuel and oxidizer whose temperature is at sub zero temperature. Turbo Pumps have to work at the vacuumed which make it more difficult to operate.

C. Injector

Injector is one of the important role which play in engine. These injector are place in the combustion chamber where it inject the fuel which come from turbo pump. Injector controls the flow of the fuel and control the mixture of fuel and oxidizer. Manufacturing of the injector is critical because injector have to inject fuel and oxidizer at low temperature. The frequency of the combustion chamber is to be maintained between 100-600 cycle per second. If this rate is affected even slightly shifted above or below it can sacrifice the whole mission. If we design injector so as to increase the specific impulse upto or more than 800 the space craft can travel into deep space for longer distance.

D. Combustion Chamber

Combustion chamber is the heart of the engine from where the power is generated. Fuel is injected into the combustion chamber by injector in finely distributed fuel droplets at very high speed. combustion take place combustion chamber which increase the pressure about 300 bar and temperature up to the 3500^0C which releases up to the thrust more than 15000 lb. This high amount of thrust is then manipulated by narrow opening towards the nozzle. The opening is kept narrow to follow law of rate of discharge which state that 'velocity is inversely proportional to area'. By this method we get the desired amount of thrust which help space craft to move in the space. In this temperature can reach upto the 3000-4000^0C and for that we have to use cooling jacket to control the temperature because metal start to deform and losses its structural integrity at such a high temperature.

E. Cooling Jacket

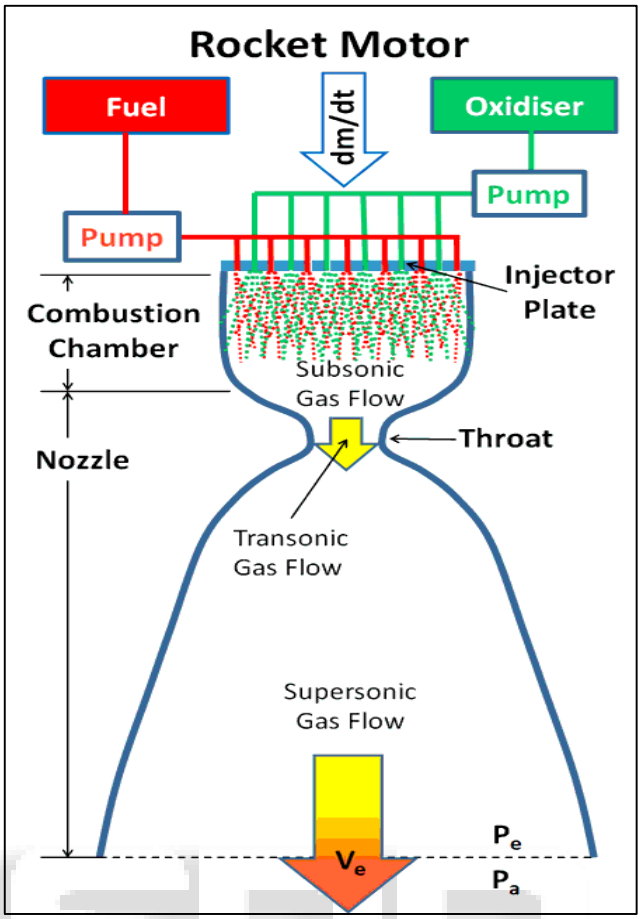
Cooling jacket is the necessary of this engine but this facility is provided by the fuel of the engine itself so no external energy is to be used. The mechanism usually used in cooling jackets is active cooling. In this Technique, the cooling jacket is made such that a flow if liquid fuel is passed this this tubes provided from between the jackets. Use of this technology throughout its journey without any deformation in combustion chamber or nozzle. To achieve the goal of successful launch of a space vehicle every component must be work in perfect algorithm.

F. NOZZLE

The pressure generated in combustion chamber can be used increased thrust by acceleration of combustion gas to high supersonic velocity. Nozzle generally passes parabolic enters. because when high velocity gases entrance and at exit of the nozzle, pressure of exhaust gas increase with high and hence velocity reduces.

G. PREBURNER

Pre-burner is the chamber where some amount of fuel and oxidizer is supply to this chamber. The exhaust of the pre-burner is supply to the gas turbine which help to run the run the turbo pumps. The pre-burner is use as an auxiliary power supply in the engine which reduce the use of the batteries in the engine.



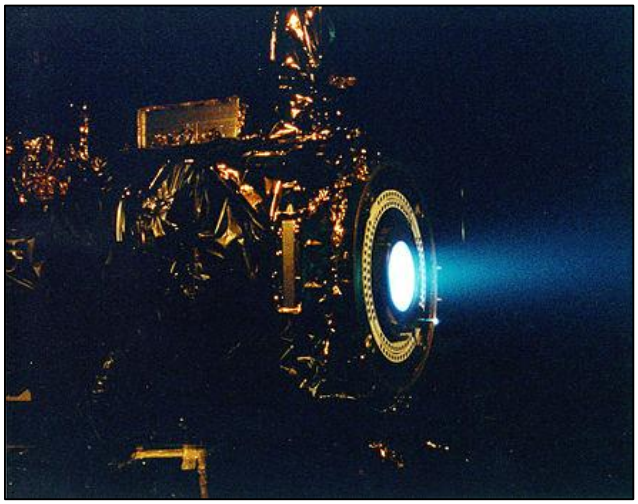
V. FUTURE SCOPE

The cryogenic engine have west scope in future we can use this technology in daily use some of the possible where we can use this engine are as follows;

1) RAILWAYS: We can use the cryogenic engine in the good carrier railways where we need tremendous amount of force to pull the heavy good which include COAL, CRUDE OIL, MILITARY EQUIPMENTS; etc...
2) AIRCRAFTS: Cryogenic engine can use in commercial aircraft but it'll be not an easy task because to control the liquid propellant and oxidizer is not an easy task . If we able to control the flow of liquid propellant and oxidizer we can easily use in daily purposes.
3) XENON ION ENGINE: Scientists are working on the technology which will replace the cryogenic engine . The major problem with the cryogenic engine is that we have to carry more fuel and this will increase the cost of the engine and may also decrease the efficiency. For that scientist are working on the new technology called 'ION ENGINE'. An ion thruster ionizes a natural gas by extracting some electron out of atoms, creating a cloud of positive ions. In thrustors in operational use have an input power need of 1-7 kW, exhaust velocity 20-50 KM/S, thrust about 20-250 millinewtons and efficiency 85-90%.

It generate thrust same as a piece of paper exert on the hand but this amount of thrust is also beneficial in the vacuum if it is continuously work. Ion engine can reach 0-100 KM/Hr in 4 days in the vacuumed which will be very helpful

in deep space mission. Ion thrusters was first use in the 'Deep Space' mission in 1998 launch by NASA which reach up to the velocity of 4.3 km/s while consuming less than 74 kilograms of xenon. space craft which uses the ion engine was 'Down' spacecraft which broke the record with the velocity of 11.5 km/s which is top speed achieve by the man made craft.



This is the actual image of the test firing of the ion thrusters for the Deep Space spacecraft at the Jet propulsion Laboratory (NASA)

VI. CONCLUSION

Cryogenic engine is an evolutionary technology which change the race of space. The country who have this technology have the upper hand on the space race and they can produce the great revenue. Cryogenic engine can give the assurance that your satellite will be successfully delivered in the orbit that we desired. This technology is important because it can use in the development of the missile because of that Missile Technology Control Regime (MTCR) is there to control the proliferation of the missiles.

Although this technology is difficult to master it can change the entire space program of the country. Injector is the main component in this engine many engine fail because of the abnormal working of the injector. Cycles of the engine also an important aspect of this technology we have to choose the cycle according to the desire of mass of payload and which orbit we want to settle the satellite.

REFERENCES

[1] Yash Muthe, Suhas Mali, Swapnil Ambekar Volume No 03, Special Issue No. 01, March 2015
[2] Swapnil Agrawal1 & Megha Kolhe2 K. Elissa, "A REVIEW ON CRYOGENIC ROCKET ENGINE," DOI: 10.5281/zenodo.1494000.
[3] Rakesh. R , Praveen. N, Prakash. "An Experimental Study of Cryogenic Engine" An ISO 3297: 2007 Certified Organization Volume 4, Special Issue 2, February 2015.
[4] Pankaj Soni, Gopal Sahu, Prakash Kumar Sen, Ritesh Sharma "A Review on Cryogenic Rocket Engine" Volume 3 Issue XI, November 2015
[5] Bhaskar Thakur, Indra Jyoti Pegu "A REVIEW ON CRYOGENIC ROCKET ENGINE" Volume: 04 Issue: 08 | Aug -2017.
[6] Akhil Chhaniyara "CRYOGENIC ROCKET ENGINE" Vol. 2, No. 4, October 2013
[7] Biblarz, Oscar; Sutton, George H. (2009). Rocket Propulsion Elements. New York: Wiley. p. 597. ISBN 0-470-08024-8.
[8] The liquefaction temperature of oxygen is 89 kelvins and at this temperature it has a density of 1.14 kg/l, and for hydrogen it is 20 kelvins, just above absolute zero, and has a density of 0.07 kg/l.
[9] The liquefaction temperature of oxygen is 89 kelvins and at this temperature it has a density of 1.14 kg/l, and for hydrogen it is 20 kelvins, just above absolute zero, and has a density of 0.07 kg/l

