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SEMI CRYOGENIC PROPELLANTS: AN OVERVIEW OF A NON TOXIC PROPELLANT FOR DELIVERING HEAVIER PAYLOADS TO SPACE

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Abstract: *Semi cryogenic fueled rockets use refined kerosene instead of liquid hydrogen, which is used in combination with liquid oxygen as the propellant in the cryogenic engine which is stored in a normal temperature. The refined kerosene needs lesser space to make it possible to carry more propellant in the semi cryogenic fuel part. Semi cryogenics is more powerful, ecofriendly and the cost effective compared to cryogenic engines.*

Key Words: *Semi cryogenics, Cryogenics, Propellant, ULV.*

1. INTRODUCTION:

Kerosene as a fuel has its advantage of burn off gas eco-friendly and cost effective and relative safety. Unlike liquid hydrogen and oxygen which has to store at -253 and 183 degree Celsius respectively, it is stable at room temperature. Kerosene is a fuel which produces line fumes in its paraffin form, it is considered environmentally friendly. It is a non-corrosive fuel, safe to store for a long time. Depending in what kind of container in which it is stored, kerosene can be kept in storage for a 1 year to 10 year. Condition have a large effect on its shell life. Kerosene runs comparatively clean and has a low carbon monoxide content and due to its lack of fuel vapor, it cannot explode.

The SCE-200 is a liquid fuel rocket engine burning liquid oxygen and refined form of kerosene that is (RP-1) is an oxidizer rich combustion cycle under development in ISRO which is expected to deliver 50 percent more thrust than other Indian Rockets. SCE stands for semi cryogenic, which needs cryogenic condition to stay in liquid form. Being an efficient lower stage having a thrust of 200 tones and controllable in flight, good enough to go in to lower stages of a large rocket.

An important feature of using semi cryogenic storage in GSLV MK-III is the payload capacity which varies from four tons to six tons. The current fuel, a combination of liquid hydrogen and liquid oxygen is heavier than kerosene but offers higher specific impulse. Also, kerosene takes up less space and more propellant can be packed in the semi cryogenic engine fuel compartment. Up till now, liquid oxygen is used as the oxidizer. Therefore, semi cryogenic engine can deliver heavier satellite into space than cryogenic engine and can also be used for inter planetary missions and deep space mission for a given weight of on-board fuel.GSLV MK 111 is a three-stage heavy life launch vehicle developed by ISRO. The vehicle has two solid strap-ons, consisting of core liquid booster and a cryogenic upper stage. GSLV MK-111 is designed to carry 4 tons class of satellite into geosynchronous transfer orbit (GTO).

Isrosene, a refined form of kerosene employed in semi cryogenic engine by ISRO were found to improve the convective heat transfer characteristic by 49% in a previous study. The specific surface area does not have any impact on the combustion characteristics, while the relative mass loading had a strong impact on the combustion characteristics.

The branch of physics dealing with the development and storage of extremely low temperature and also its effect on various substances is known as cryogenic. The semi cryogenic engines will be used as the booster engine for the common liquid core of the heavy lift Unified Launch Vehicle (ULV) and Reusable Launch Vehicle (RLV). The liquid stages of PSLV and GSLV engines uses toxic propellants that are harmful for the environment and it's high time to change over to eco-friendly propellants.

Only the second stage of the launch vehicle GSLV MK III is replaced, which uses liquid fuel with the semi cryogenic engine the rocket will retain the cryogenics in the upper third stage. However, the semi cryogenic engine has lower specific impulse, than cryogenic engines for about 100 seconds and to overcome this burden their needs a rapid development of new stages with multiple clustered semi cryogenic engines. Throttling of liquid engine is another major working field to be considered. The lower stage throttling helps in easing maximum Q pressure on the vehicle during the initial part of the launch. Upper stage throttling provides the vehicle with various orbit insertion capabilities.

2. Semi cryogenic engine pre-burn single element:

Combustion modeling of single element coaxial bi- swirl injector of semi cryogenic preburn was carried out to understand flow and flame characteristics at hot test condition. LOX is introduced through four tangential inlets and 12 axial inlets at HTK. Kerosene is introduced from four tangential inlets at 340K in clockwise direction. A full three-dimensional domain of single element is created with appropriate boundary condition.

The flame structure is governed by flow characteristics, which in turn will affect the temperature pattern in the domain shear layer in semi cryogenic engine to extend the main combustion zone, where it interacts to form high combustion region with maximum flame temperature of 3300 K.

Many of the current rocket engines work in toxic propellant combination like monomethyl hydrazine (MMH), nitrogen tetroxide (N2O4) Unsymmetrical Dimethyl hydrazine are difficult to handle. Any failure using this propellant have catastrophic implication on environment. There is an increased drive to explore environment friendly propellants. Several developmental activities have been taken up to acquire knowledge in design of thrust chamber injector which is a vital element that govern the engine performance and the main chamber life. The engine is designed to operate from 60% to 105% of nominal level.

The major subsystem of the engine are Thrust Chamber, Pre-burner, turbo pump, thrust and mixture ratio control system feed circuits and flow control components. Pre burner produces oxidizer rich hot gas at high pressure to drive the turbine. The exhaust gas from the turbine is then injected to the thrust chamber. The thrust chamber is a combustion device where the propellant are metered, injected, atomized, mixed and burned to generate hot gas which is accelerated and ejected at high velocity to impact thrust. A thrust chamber includes three major parts, an injector, combustion chamber and nozzle. Ignition in thrust chamber is initiated using hyperbolic slug (mixture of Tri ethyl Aluminum and Tri ethyl Boron) contained in the ISR feed circuit serves on the ignition source.

Injector: The injector is designed to as a coaxial swirl type element, for better atomization, mixing of propellants and uniform distribution of propellants. The design of injector element is obtained experimentally and mainly depends on testing experience. Evaluation of injector performance at main engine level testing in costly and time consuming. An injector head with a single base element has been configured to work an oxidizer rich hot gas and LSR combination, to characterize of injector element.

Thrust chamber is basically configured with two types of injector elements – Nominal (base) and protruding element. The nominal injector elements are forced to deliver oxidizer rich gas through a long post with flow controlled with an orifice and fuel through 12 tangential holes arranged in 2 rows (each 6 no's). The element is provided with 12mm recess length. These elements consist of the full 3 parts namely orifice, made of nickel-based alloy to check for compatibility in oxygen rich medium at high temperature, post and bush made of steel connected together by orbit welding fuel enters through bush part of the assembly. Various experimental activities evolve improved propellants, structural materials and design combination of several kinds of engines and motors choosing according to their function but one major challenge is to achieve reliability corresponding to the value of the payload because of the performance advantage of energetic propellant and low thermal mass propulsion system they provide operation near their safe limits.

3. Development of rockets:

Various experimental activities involved improved propellants, structural materials and design, combination of several kinds of engines and motors, chosen according to their function. Because of the favorable functioning of energetic propellants and low structural mass in a propulsion system provide operation near their safe limits but one major challenge is to attain reliability corresponding with the value of the payload.

To overcome Earth's gravity for travel to outer space destination, the spacecraft must be accelerated to a velocity of approximate 40,000km/hr. A rapid initial acceleration is required to minimize both the time that a launch vehicle takes to transmit the stressful environment of the atmosphere and the time during which the vehicles rocket engine and other system must operate near the performance limits. To accomplish rapid acceleration space vehicle requires one or more rocket engine burning large quantities of propellant at higher rate to launch from earth atmosphere to attain orbital velocity within 8 to 12 minutes. A launch from earth's surface or atmosphere usually attain orbit at velocity within 8 to 12 minutes. Such rapid acceleration requires one more rocket engine burning large quantities of propellant at a higher rate, while at the same time the vehicle must be controlled so that it follows its planned trajectory. To upgrade the mass of the spacecraft that a particular launch vehicle can carry, the vehicles structural weight is kept short as much as possible. Most of the weight of the launch vehicle is actually its propellants, i.e, the fuel and the oxidizer required to burn the fuel.

Kerolox is the liquefied and highly refined kerosene. (RP-1). The advantage of using kerolox is that it is 10 times dense meaning the same volume of kerolox will generate more thrust than the same volume of hydrolox and less hazardous than it. With increase in payload capacity, the advanced GSLV MK111 will help ISRO was expenses and save time.

4. Cooling of semi cryogenic:

In the case of upper stage engines change of kerosene regenerative cooling with oxygen allows a significant increase of achievable specific impulse. The rise of propellant average density is considered as an added advantage for mixture ratio optimization. Analysis shows that combustion of oxygen regenerative cooling and semi expander cycles allow creating the oxygen kerosene propulsion system with minimum specific impulse losses.

Without film cooling, the heat flux is maximum at the throat and it reduces by 54% when film cooling is provided. When film cooling is provided there is considerable reduction in heat transfer from the combustion gas to the walls of the thrust chamber.

For semi cryogenic engine the coolant used for regenerative cooling s refined version of kerosene equivalent to RP1. The kerosene is a mixture of hydrocarbons. During passing through the coolant channels, the temperature of the kerosene increases. However when the kerosene comes in contact with high temperature walls, it decomposes and leaves behind a sticky rubber like substance called as coke. The coke can clog the injector element holes which are very small in size. Hence the cooling characteristics are to be studied thoroughly for different operating conditions.

Development of a special grade of kerosene suitable for rocket engine was one of the improvements done to the engines being developed by the Navaho and Atlas missiles. By January 1956, Rocket dyne, designed for incorporation into the experimental Naval so cruise missile had produced a version containing 3 firing chamber that generate a thin aster ending 415,000 pounds of thrust burning LOX-Kerosene (the XLB83). Unlike Titan missile, which had a different first stage engine, built by aero jet, burned LOX-Kerosene fuel instead of LOX- Alcohol.

Saturn V was built to place 3 astronauts on the moon and allow them to take sufficient fuel and equipped to return to earth which has 363 feet high and weighing 5, 00,000 pounds unfueled, was capable of launching more than 200,000 pounds to low earth orbit. The Saturn V consist of 3 stages, The S-IC 1st stage (powered by five F-1 LOX Kerosene engine), the S-II 2nd stage propelled by five J-2 LOX-LH2 engine and the S-IVB third stage with one J-2 engine.

In January 1959 Rocket dyne, NASA received the contract to build 7-1. The contract for the giant power propeller plants which would employ RP Kerosene-LOX stimulated that it should develop 1.5 million pounds of thrust nearly 4 times the thrust of NAVO missile from which it was derived.

The RD-107 was derived from captured German V2 rocket engine technology. Instead of using more exotic and energetic combination like liquid oxygen hydrogen RD-107 uses LOX-Kerosene propellant combination unlike regeneratively cooled US designs where the thrust chambers are not constructed from the bundles of tools but are made of low grain stainless steel copper lining.

Realization of semi cryogenic engine involves the development of performance critical metallic and nonmetallic materials and related processing technologies. 23 metallic materials and 6 nonmetallic materials have been developed.

By adjusting the fuel and power level stages, a single launch vehicle can be used to launch various payload and thus element wise the requirement to have multiple launch vehicle, this is the sole of the ULV project.

5. Cryo-propellent tanks :

Satellite launch vehicle put an artificial satellite in orbit to circle around the earth and is used for communication and remote sensing. The upper stages of many launch vehicle are cryostage i.e., stages that are liquid hydrogen LH2 and liquid oxygen LO2 as propellant to generate thrust, the tank material should have sufficient ductility and feature toughness at low temperature apart from high specific strength. The tank contains the propellant under pressure and are subjected to flight, axial, shear and bending loads. Since they form the core part of the vehicle. The factors considered while designing the tanks are for presence, flight load and thermal load, they have to be extremely light and reliable. Axisymmetric modeling and analysis of the cryo propellant tank is done by using ANSYS.

Semi cryogenic engine render the greatest thrust to weight ratio. Higher density of the exhaust gases of the semi cryogenic supply high mass flow rates making it easier to develop high thrust engines. Hence it can be concluded that semi cryogenic engine is ideal for lower stages.

6. Drawbacks of cryogenic propellants :

- Some cryogenic fuel like LNG are naturally combustible. Ignition of fuel splits could result in large explosion.
- Cryogenic storage tanks must be able to withstand high pressure. High pressure propellant tanks require thicker walls and strong alloy which makes the vehicle tanks heavier thereby reducing performance and practicability.
- Despite nontoxic tendencies, cryogenic fuels and dense than air. As such, they can lead to asphyxiation. If leaked, the liquid will boil into a very dime, cold gas and if inhaled could be fatal.

Instead of using more exotic and energetic combination like LOX-H2, RD-107 uses liquid o2-kerosene propellant combination. Unlike regeneratively cooled in designs where the thrust chamber is not constructed from the bundles of tube, but are made of low-grade stainless steel with the lining.

In the case of upper stage engine optimization of mixture ratio by replacing a kerosene regenerative cooling with oxygen allows a significant increase of achievable specific impulse. The increasing of propellants average density is considered as an additional benefit of mixture ratio optimization. Various analysis show that most feasible and favorable option for oxygen regenerative cooling of thrust chamber between Oxygen kerosene engines. Combustion of O2 kerosene propulsion system with minimum specific impulse losses.

Characterization of injector elements and hyperbolic slug injection with different proposition of tri ethyl aluminum and tri ethyl boron has been done.

Rectangular rings, gaskets and o rings for control component and turbo prop of semi cryogenic engine as well as tri ethyl aluminum based hypergolic ignite has been developed. Hot tests were caused with LOX step injection mode on semi cryogenic pre burner injector at high pressure after completing cold flow trials and sequence validation tests.

7. ULV (Unified Launch Vehicle):

The ULV is a future expendable launch vehicle concept in base the GSLV MK-III its modular in shape, comprising semi cryogenic as core stage, a cryogenic as upper stage and straps of different magnitude mode of solid rocket. It can be S-200, S-13.8 user, depending upon the payload requirement.

Unified launch vehicle will use a common semi cryogenic stage and will have the feature of a world class expendable launch vehicle, with maximum G70 load capability of 6t and maximum LEO payload capability of 15t.

The Growth of Unified Modular Launch vehicle focus to lessen the number of propulsion modules from all the three types of launch vehicles (PSLV, GSLV, MK-2, and LVM3). This would mean than the core vehicle would be a standard configuration of cryogenic and semi cryogenic and depending upon the payload mass to be delivered in orbit, the solid strap on boosters with different loading would be added.

It is conceived to be ideal at lower internal pressure. The SCE-200 is a single chamber dual main engine with single burn turboprop propellant supply system.

Vaccum brazing done by joining two shells is required to manufacturers of thrust chamber and pre-burner of semi cryogenic engine as per the new brazing process for semi cryogenic engine established by ISRO. The inner shell is made of a Cu alloy, whereas the outer shell is made of stainless steel. The inner shell has ribs in its outer surface which needs to be joined to the inner shell. Moreover, an outcome of this brazing process is an arrangement of active cooling channels in the final equipment.

The mixing process of internal flow is very important in a received swirl coaxial injector. Swirl coaxial injector offers easier fabrication efforts, providing cost and schedule saving for hardware development. Swirl coaxial elements also offer some flexibility for design changes. Analyze of liquid oxygen and liquid methane propellants at MSFC proved that a swirl coaxial injector provide improved performance compared to an impinging injector. So technical interest was generated to see if similar performance gains would be achieved for LOX&RP-7 using a swirl coaxial injector.

The fuel pump is drawn in a conventional manner for example using a fuel rich gas generator cycle. Estimation of staged combustion cycle based on oxygen rich pre-burner indicated that one of the proposed semi expander cycle has a simple impact only on 0.4% lower while providing much lower oxygen temperature, more efficient tank pressuring system and built roll control. Semi expander cycle can be assessed as a more stable and productive in relation to its cost. Additionally, there are uncertainties in the choice of propellants combustion chamber presence and many other engine parameters for obtaining an optimal outcome. In this active, the possible ways of optimization of upper stage liquid rocket engine operating on liquid oxygen LOX are kerosene are considered.

Typically the thrust chambers of LOX/ Kerosene engines are regeneratively cooled by kerosene. Use of such cooling is usually supplemented by so called “internal cooling”. Internal cooling is based on the reduction of near wall temperature of combustion gas. This can be accomplished either by kerosene film cooling or by special arrangement of propellant injector. As a result the inevitable specific losses occur due to non-optimal overall and local mixture ratios. Such losses are worse for the lower thrust engine found in upper stage. Analysis of possible engine layout.

While considering the engine layout, it is important to take in to account not only the achievable specific mass and weight limits but also the losses created by thrust vector control and tank pressurizing. Because in some cases, such extra losses can negate the benefit of engine layout.

8. CONCLUSION:

The salient features of semi cryogenic propellant is that it offers staged combustion cycle for high performance, cost efficient and the use of eco-friendly propellants is also 15 times reusable for RLV. The semi cryogenic engine which uses a combination of cryogenic s well as earth storable propellants can develop a thrust of 2000KN.

The first stage of the Reusable Launch Vehicle Technology Demonstration Program (RLV-TD) which is a winged vehicle that will take off like a rocket and glide back to land like a plane will be powered by a semi cryogenic winged booster capable which is capable to fly back and land on a runway near the launch site.

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