International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2020): 7.803

A Review on the Development of Various Types of Rocket Propellants

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Abstract: ***Space exploration is one of the most amazing endeavours that man has ever undertaken. One of the biggest challenges in rocket launching lies in the selection of appropriate propellant. In recent years, there is an emerging trend in the development of various types of propellant, as the most crucial part in space research is the choice of propellant used which determines the performance of the space vehicle. Here in this article, we present an over view on different types of propellant which is used in rocket like solid, liquid, gas, and hybrid propellant. A systemic study on various chemical and physical properties of the material enables us to understand their behavior in various extreme conditions. These analysis help us to predict the efficient fuel suitable for the rocket engine thereby satisfying the basic parameters such as environmental safety, high performance and low cost.***

Keywords: Rocket propellants, Solid propellant, Liquid propellant, Gas propellant, Hybrid propellant

1. Introduction

Propellants are chemical compounds or mixtures that are capable of combustion without air as an oxidizer. Mainly there are three types of propellants: solid, liquid and hybrid propellants. Propellants are usually classified according to their functionality. Some of the examples are: liquid hydrogen and oxygen, hydrazine, kerosene, ammonium perchlorate, HTPB (Hydroxyl terminated polybutadiene), PBAN (polybutadiene acrylonitrile) rocket fuel, methanol, salts, etc. There are certain parameters which need to be considered for a substance to be a good propellant. These are specific thrust, regression rate, specific impulse, temperature, pressure, combustion, burning, gases evolved, boundary velocity diagram, granular arrangement, molecular distortion, hardness, tensile strength, weight, density impulse, viscosity, flow ability, kinematics etc [1]. Hence a detailed study on the propellants is essential to develop the future propellant with better characteristics.

2. Development of various type of propellants

1) Solid Propellants

Solid propellants (SPs) have been originally designed to power rocket engines in aerospace. Fuel and oxidiser are the two basic elements that constitute a propellant. The property of these SPs can be enhanced by additives such as nano particles - (graphene, carbon nanotubes) [2]. The first roadmap for solid propulsion space applications [3] presented solid propulsion's major advantages of simplicity, cost effectiveness (impulse vs. total cost), and reliability (relative to liquid rockets (LRs)). The first solid propellant used is Black powder also known as gun powder [4], [5].

In both defence and space applications, a solid propellant based rocket motor is preferred over a liquid/hybrid rocket motor due to the following advantages: simple construction, mobility, high thrust capability, readiness to launch on short notice and relatively moderate storage conditions. Solid propellant is a solid phase mixture of oxidizer and fuel which releases the required energy for propulsion on combustion. Solid propellants are broadly classified into two categories namely: 'homogeneous' and 'heterogeneous' propellants. In a homogeneous solid propellant, fuel, oxidizer, stabilizer and plasticizers are mixed at the molecular level to form a colloid and the ingredients are indistinguishable after mixing. Depending upon the number of active substances (that release energy upon combustion) in the composition, a homogeneous solid propellant can be single - base, double - base or triple - base. Double - base propellants are used in anti - tank missiles and short - range surface - to - air missiles. Composite solid propellants (CSPs) are the heterogeneous multi - modal mixtures of oxidizer (micron size particles), binder (polymer based), metal & metalloid fuel additives, plasticizers, chain extenders, ballistic modifiers and antioxidants. Composite solid propellants are frequently used for long - range strategic missiles due to the steady burning rate, higher specific impulse, and higher specific density [6], [7].

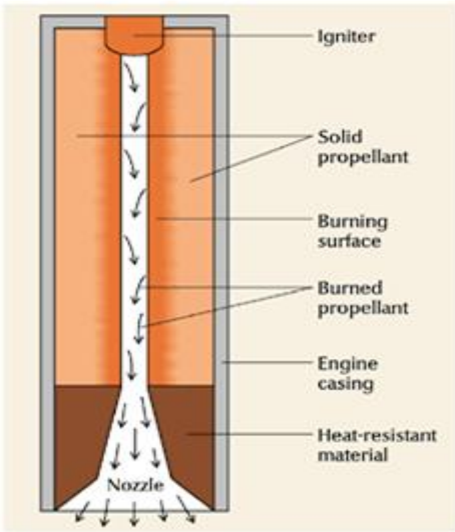

Figure 1: Basic principle of solid rocket engine

2) Liquid propellants

A liquid - propellant rocket or liquid rocket utilizes a rocket engine that uses liquid propellants. Liquids are desirable because they have a reasonably high density and high specific impulse (Isp). This allows the volume of the propellant tanks to be relatively low. Liquid - propellant systems carry the propellant in tanks external to the combustion chamber. Most of these engines use a liquid oxidizer and a liquid fuel, which are transferred from their respective tanks by pumps. The pumps raise the pressure above the operating pressure of the engine, and the propellants are then injected into the engine in a manner that assures atomization and rapid mixing. Liquid - propellant engines have certain features that make them preferable to solid systems in many applications. These features include (1) higher attainable effective exhaust velocities (ve), (2) higher mass fractions (propellant mass divided by mass of inert components), and (3) control of operating level in flight (throttle ability), sometimes including stop - and - restart capability and emergency shutdown. Liquid systems also have been used extensively as first - stage launch vehicles for space missions, as, for example, in the Saturn (U. S.), Ariane (European), and Energia (Soviet) launch systems [8].

Hydrazine is the most effective liquid propellant. Its derivates with dinitrogen tetroxide, N2O4 is used as the rocket propellant [9]. These are monomethyl hydrazine, (CH3) NH (NH2) MMH and unsymmetrical dimethyl hydrazine, (CH3) 2N (NH2) UDMH. UDMH stands for unsymmetrical dimethyl hydrazine. This propellant is hypergolic in nature. Its chemical formula is H2NN (CH3). It has melting point of 221 K and boiling point of 337.1 K with density of 0.791 g/ml. This propellant is very stable and can be kept in rockets for longer time. It can provide specific impulse of 277 s. Various oxidizers like oxygen, hydrazine, fluorine, nitrogen tetroxide, chlorine pentaoxide, nitrogen oxide, hydrogen peroxide. Are used with various corresponding fuels such as MMH (monomethyl hydrazine), UDMH, MON (mixed oxides of nitrogen), AEROZINE, hydrogen, lithium, hydrazine, HTPB [10].

The relative merits of solid and liquid propellants in large launch vehicles are still under debate and involve not only propulsion performance but also issues related to logistics, capital and operating costs of launch sites, recovery and reuse of flight hardware, and so forth.

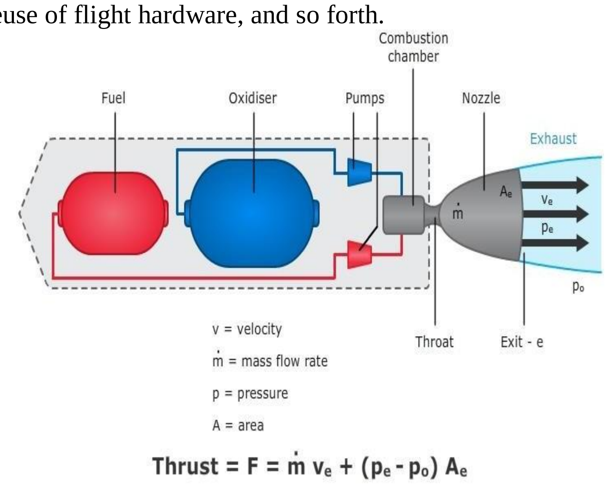

Figure 2: Basic principle of liquid rocket engine

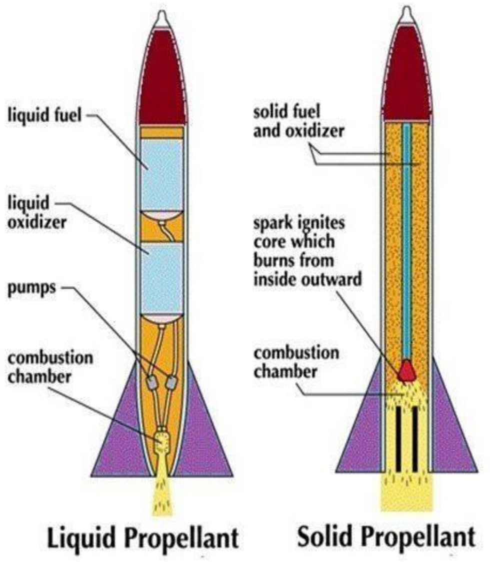

Figure 3: Comparison of solid and liquid rocket propellant

3) Gas propellant

Gaseous propellants are the fuel in gaseous state of matter. These propellants are usually used in compressed form. These are of low density and need high weight pressure vessel. Various compressed gas such as halogenated hydrocarbon, nitrous oxide, oxygen; hydrogen, carbon dioxide etc are used as gas propellant. These are used in various industrial sectors such as pharmaceutical, food processing, electrical and electronics industries etc. Liquid hydrogen, oxygen, hydrazine, etc can be used in gaseous phase. Hydrogen is chemical reactive with high diffusivity and high cooling capacity. Use of liquid hydrogen in the booster at the top stage has increased the efficiency of space load. Hydrogen propellant can increase the specific impulse of nuclear rocket. Liquid hydrogen has low specific gravity and bulk density. Its auto ignition temperature is 500 °C. To maintain pressure balance the storage tank of large size are used [11]. Gaseous oxygen is used as an oxidizer but not as a fuel perspective. It reacts with metal cylinder in which it is kept and hence can cause corrosion. Pure oxygen can't be kept at high pressure, hence proper maintenance is required.
Hence gaseous propellant has various problems like less dense nature, storage problems, volatility difficulties, explosion characteristics and economic considerations. Hence gaseous propellant is never thought of being used as fuel and rather do any research is going on in this field.

4) Hybrid propellant

Hybrid rocket propellant is newly advanced propellant in which solid fuel and liquid oxidizer are combined for combustion to take place. Hybrid rocket motors are a form of chemical propulsion system where the fuel and oxidizer are stored in different phases. The typical hybrid motor configuration uses a solid fuel grain and a liquid or gaseous oxidizer. The most common oxidizer used are N2O4 (dinitrogen tetroxide), UDMH, CH4, LH2 (liquid hydrogen), LOX (liquid oxygen) etc., And the most common fuel used are: HTPB, gunpowder and polyethylene. Further there are various other substances which are into research such as paraffin wax with additives like aluminium, carbon nanotubes and graphene [12], [13].

Paper ID: SR211102114138 DOI: 10.21275/SR211102114138

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The advantageous nature which differentiates it from other two types of propellant are low density, less space for storage, more thrust and cost effectiveness. But the disadvantage is that the solid propellant after complete burning, leave some residue particles in the chambers which reduces the acceleration or thrust at the end to quiet an extent result in lowering of efficiency of propulsion [14].
However various space agencies are working on hybrid propellant but it is yet not a reliable one for the space agencies to use for space exploration. Various space rocket manufacturing companies and universities are into deep research to provide an alternative source of rocket propellant for space exploration which can open new dimensions in the field of propellant or substance under consideration to be used as propellant.

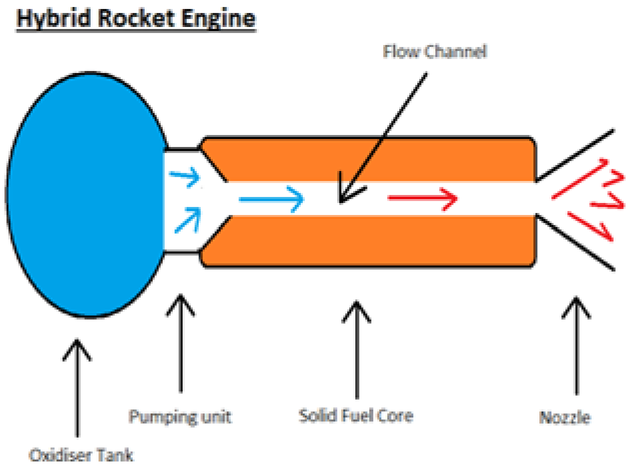

Figure 4: Hybrid rocket propellant

3. Conclusion

From the above studies we can see that Liquid propellant is the most reliable propellant among the others. But hybrid propellant can be considered in future reference as an alternative source of propellant. Recent studies are also towards reducing the use of hydrazine and toxic propellant. Environment pollution and human safety are the foremost concerns regarding the choice of propellants and green propellant of ethanol, hydrogen, oxygen, kerosene, paraffin wax, HTPB may be the alternative. Nowadays, the rocket propulsion is conducted by ion exchange transfer which is a promising research where, in the presence of magnetic field, electrons of inert gases are collided with positive ions to produce thrust for a longer period. Paraffin wax can also be used as an alternative if aluminium is doped with it which can provide high regression rate. Further, carbon nanotubes or graphene can also be considered. Hydroxyl Ammonium Nitrate (HAN) - based green propellants and an understating of the combustion mechanism of other high energetic liquid propellants emerge as the promising step towards the future development of propellants.

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Author Profile

Shrisudha Viswanathan is a Scientist turned Entrepreneur with a longstanding passion for education. A Gold medalist from Anna University, Chennai she holds M. Tech degree in Polymer Science and Technology. Also a former scientist of Indian Space Research Organization (ISRO), she had carried out research in the frontier areas of NanoTechnology. She was also a team member in the Space Capsule Recovery experiment (SRE), identifying research activities for future programs of ISRO. An Academic Coordinator of Science India Forum, UAE (A Vijnana Bharati Initiative), she helps to identify and motivate young students having flair for Science and Technology. She is a public speaker and presenter, delivering webinars and sessions on space education and motivational topics to thousands of teachers across the gulf as well as parent community. Recently she was honored by Aatmanirbhar Bharat (ANB), as the best mentor on the topic of 'Space and Drone flying policy' of India

Dr. Karthika Chandramohan is an entrepreneur, educationist and a researcher having a strong passion towards innovation, research and Women empowerment. Holding a Doctorate degree in Chemistry from Bharathiyar University, Coimbatore, India, she is not only an Entrepreneur but also an avid researcher. Her main area of research is in the field of Environmental Chemistry, specifically in waste water treatment / desalination using ion exchange resins and activated carbon. She has a commendable experience in composites, resins and also in searching/ drafting patents (USPTO/ EPTO etc.,) to update and improve R & D activities. Apart from paper publications she has presented her papers in several International events including ICBEC, ECPAC, NCCTC, NCRTPST, INCCOM and also chaired a session at the International conference, ICBE, Dubai, UAE. She is a Lead guest editor for Science publishing group, USA and also a peer reviewer for Elsevier's Journal of Environmental and Chemical Engineering and Journal of Saudi Chemical society, Elsevier. Recently she was awarded 'OUTSTANDING REVIEWER' by JECE, Elsevier