International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Review on Applications of Fluid in Rocket Science (Fuel)

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Abstract: ***The greatest revolution in human life is born from science. The Universe has four primary forces: gravity, electromagnetic, weak, and strong nuclear forces. The Industrial revolution started from unrevealing forces of the universe. The discovery mathematics of gravity and three laws of motion by Isaac Newton led the industrial revolution, steam engines, pulleys, and machineries. They all operated on well-defined laws of motion. The gravity helped to understand the heavens. The discovery of electromagnetic force by Faraday and Maxwell led to era of electricity and communication. It led to invention of electric plants that lighted up whole world. The motors, dynamos, transformers made our industrial production automated. The nuclear force led to thermonuclear power plants, explained why stars shine. The quantum mechanics led to invention of lasers, transistors, computers. The theory of relativity helped in invention of GPS etc. The human life is being made more luxurious as ever if the principle of science is flourished, valued, analyzed, applied, and implemented. The mechanical branch deals with the force. In every machine, the input force (work) is being multiplied, changed its direction, or modified in such a way that its output is always greater. It uses various physical factors like temperature and pressure to achieve above criterion. On this regard, to maintain the operation, fluids (liquid or gas or both) have proved most important.***

Keywords: Gravity, Industrial Revolution, steam engines, GPS, fluids

1. Introduction

After the World War II, many nations suffered brutal defeat, creation of new nations but the sense of competition among the massive countries didn't end even when the war ended. One such example is the political hostility between the Soviet and the United States known as Cold War. It was since that time human has been venturing the space (since October 4, 1957) when the Union of Soviet Socialist Republic (USSR) launched Sputnik I the first artificial satellite to orbit earth. After the successful orbiting of Sputnik I, around the earth in 1957, considerable efforts have gone into space exploration and its uses [4]. This was also highlighted by the human footprint on the Moon in 1969 under the Apollo program. One year later NASA launched their first human space flight program called Project Mercury. From that point the time of space age started. Therefore, the Cold War can be described as 'Blessing in disguise, ' for space exploration era.

The Space Missions required space vehicles to carry their astronauts to orbit or moon. The launch of artificial satellites for different purposes like communication, space observatory, telescopes, weather observatory, GPS, military required rockets to station them in their desired orbits with desired time and orbital velocity. This has led to scientists, astrophysics, engineers, various manufacturing companies of various countries to build various spacecrafts the most complex machines they have ever built. The engineering works involved application of various engineering sciences, concepts, mathematics, theories, and research conclusions to make the creation happen into reality. In this regard, the concept and applications of fluids has been most important in every part of design. One must note that every fuel, liquid, or gases used in operation of rockets comes under fluid. Therefore, the word 'fluid' needs to use with reference to their state of existence (either liquid or gas).

Rockets work based upon Newton's third law of motion. For the rocket to rush forward, something must rush backwards. The propellant is a substance that spews from the spacecraft's back end, providing propulsion (or a push forward). The propellant is frequently a type of fuel that is burnt with an oxidizer to generate massive amounts of extremely hot gas. These gases grow until they rush out the rear of the rocket, propelling it forward. Sometimes, instead of being burnt, the propellant is ejected directly out of the spaceship, creating propulsion. The propellant in ion propulsion is made up of electrically charged atoms that are magnetically forced out of the spacecraft's rear. A compressed gas is pumped out of the spaceship for smaller attitude control thrusters.

2. History of the Rockets Fuel

Solid Propulsion

Rocket propellant is the fuel utilized by a spacecraft to provide thrust (upward force against gravity). The propellants commonly comprise of fuel and oxidizer that chemically interacts to produce extremely hot gases. These gases exert pressure that propels the rocket forward [7]. The history of solid rocket propulsion started more than 2000 years, during an accidental discovery of black powder around 220 BC ca in China and continues at the present. The history of solid propellant dates to13th century in China. The Song Chinese first used gunpowder in 1232 during the military siege of Kaifeng [8, 9]. Gunpowder was the first chemical explosives, dating back to the first millennium AD (or less often coal). Because it was difficult to compress large quantities of gunpowder without adding cracks or holes that caused damage, ordnance-employed gunpowder was confined to modest propellant grain sizes. erratic combustion [3]. The idea of black (or gun) powder moved from East China to India, Korea, Arab countries, Europe, and finally reaching to USA [1].

Solid propellants are energetic materials used to launch and propel rockets and missiles [3]. The history of solid-and liquid-propellant is especially difficult to study, including the technical complexity of the lively applications and the resultant division of labor among rocket engineers of various disciplines and subdisciplines. Adding to above reasons, it also includes the huge number of firms that have manufactured various technologies and spare parts to numerous large and small rockets and missiles. The rockets and missiles were recruited largely by U. S. Army, U. S. Navy, U. S. Air Force, NASA, and a growing commercial private sector [2].

The advantages of solid rocket propellants are: (1) simplicity in using which yields benefits in maintenance costs and savings in systems of high production rates; (2) stability for storage, with long service lifetimes (as long as 30 years); (3) resistance to unintended detonation; (4) reliability, related to their simplicity and chemical stability; and 5. high mass flow rates during launch, and consequently high thrust, a genuine requirement for the initial phase of missiles and rockets, which uses solid propellant boosters. However, disadvantages of solid propellants are the difficulty in varying thrust on demand (i. e., solid fuel rockets generally cannot be throttled or operated in start-stop mode) and relatively low specific impulse (time integral of the thrust per unit weight of propellant), in comparison with liquid fuel motors [3].

Liquid Propulsion

Liquid-propellant Rocket Systems carry the propellant in attached externally to the combustion chamber. The 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 [10]. About 170 different propellants have been tested, excluding minor changes to its component such as additives, corrosion inhibitors, or stabilizers. In the U. S. alone not less than 25 different propellant combinations have been developed and instituted in the space craft. As of 2020, no completely new propellant has been developed and used since the mid-1970s [11].

Konstantin Tsiolkovsky (1903) proposed the application of liquid propellant in his "*Exploration of Outer Space by Means of Rocket Devices.* "The liquid oxygen and petrol rocket for first partially successful liquid-propellant rocket launch on March 16, 1926 was used by Robert H. Goddard. Both propellants preferred due to its cost effective, availability and high calorific values. Oxygen is a moderate cryogen which can be stored without excessive insulation during space mission [12, 13].

The advantages of liquid propellants are that they have higher specific impulses than solid propellants, thrust can be throttled and system can be restarted whenever as wanted. Moreover, the flow of propellant can be monitored and regulated those results in accurately controlling the magnitude of thrust [5]. They have been uniquely suitable for controlling attitude changes and minor velocity changes of individual stages space program. A precise repeatable thrust is required to ensure precise terminal velocity, important in missiles, precise orbit insertion, and military missiles. Many LPREs can be functionally checked out and even fully tested before the launch [14].

General Features of Liquid Propellant

Chemical propellants deliver specific impulse values starting from about 175 up to about 300 seconds. The theoretical capability of specific impulses of most propellant ranges up to about 400 seconds. The requirement of the high specific impulse is high exhaust temperature with low molecular weight. The criterion of propellant is that it should have high enthalpy of combustion to yield high temperatures, and combustion products should contain simple, light molecules such elements as hydrogen, carbon, oxygen, fluorine, and thus the lighter metals (aluminum, beryllium, lithium).

The second important factor is that the propellant density. A given weight of dense propellant is carried in an exceedingly smaller, lighter tank than the identical weight of a low-density propellant. Liquid hydrogen is energetic and its combustion gases are light but thanks to bulky and heavy they require large tanks. The dead weight of those tanks partly offset the high specific impulse of the hydrogen propellant.

Table 1: List of cryogenic liquid propellants [16]

Propellant	$O/F_{optimum}$ [-]	Flame Temp [ºC]	Vacuum Specific Impulse [s]
Oxygen + Hydrogen	3.8	2530	435
Nitrogen Tetroxide + RP-1	3.5	3000	297
90 % H2O2 + RP-1	7.0	2500	298

But high values of impulse are not always favorable. It creates complication in operation of engine. Some aren't adequate as coolants for the new thrust-chamber walls. Others portray a unique combustion characteristic that has no proper application. Some are unstable to varying degrees and can't be safely stored or handled. Such features inhibit their use for propulsion.

The disadvantages are most propellants are corrosive, flammable, or toxic or combination of all. One among the foremost tractable liquid propellants is gasoline. But while it's comparatively simple to use, gasoline is, of course, highly flammable and must be handled with care. Many propellants are highly toxic and corrosive that only some special substances can be wont to contain them; some may burn spontaneously upon contact with air, or upon contacting any organic substance, or in certain cases upon contacting most typical metals.

Also essential to the selection of a rocket propellant is its availability. In some cases, to get adequate amounts of a propellant, a completely new manufactory must be built and since some propellants are utilized in very large quantities, the provision of raw materials must be considered [15].

Types of Liquid Propellant and Oxidizers (Room Storable Liquid, Cryogenic and Monopropellant)

Table 2: List of room storable liquid propellants [16]

Reactant	Formula	Type	Density [kg/m^3] (20 °C)	Characteristics
87.5% Hydrogen peroxide	$0.875H_2O_2 \cdot 0.125H_2O$	Oxidizer	1376	Transparent, decomposes, monopropellant, non-toxic.
Nitrogen Tetroxide	N_2O_4	Oxidizer	1440	High density, narrow temperature range, very toxic
Nitric Acid	HNO_3	Oxidizer	1549	Corrosive, wide temperature range.
Hydrazine	N_2H_4	Fuel	1005	Very toxic, monopropellant, low density, low temperature range.
RP-1	$CH_{1.97}$	Fuel	580	Broad temperature range, low cost, very low density.
Unsymmetrical Dimethylhydrazine (UDMH)	$(CH_3)_2NNH_2$	Fuel	856	Broad temperature range, very toxic.
Methane	CH_4	Fuel	424	Broad temperature range, very toxic.

Table 3: List of Monopropellants [16]

Reactant	Catalyst	Decomposition temperature (°C)	Specific Impulse (s)	Characteristics
87.5% Hydrogen peroxide	Silver	670	150	Non-toxic, medium performance, temperature, and low cost
Hydrazine	Shell405	1100	230	Very toxic, high performance and high cost.

Application of Liquid Propellants in Cryogenic Rockets

A cryogenic rocket engine uses cryogenic fuel or oxidizer, where fuel or oxidizer (or both) are gases liquefied and stored at very low temperature. Specific impulse of cryogenic propellants (liquid Hydrogen and liquid Oxygen) is much higher compared to storable liquid and solid propellants, giving it a substantial payload advantage. Oxygen liquefies at-183℃ and Hydrogen at-253℃ also requires complex ground support systems like propellant storage, cryo engine and test facilities, transportation services, and handling of cryo fluids and related safety aspects of crews [17].

The Indian Space Research Organization (ISRO) is using the highly toxic and corrosive fuel UDMH (Unsymmetrical Di-Methyl Hydrazine), along with the oxidizer nitrogen Tetroxide (dirty combination). The fuel is used in the core (or the middle unit of the lower part) of the GSLV Mk-III, the rocket used in the Chandrayaan-2 mission [18].

3. Conclusion

The space exploration has become one of the important means of vast scientific researches and finding of extra-terrestrial lives. For this to achieve, rockets (Space crafts) are required which is powered by different rocket fuels. The rocket fuel is liquid propellants which is fluid. The fluid is not only used as the rocket fuel but also for different mechanisms such as cooling and hydraulic applications.

References

[1] T. DeLuca L. CHEMICAL ROCKET PROPULSION.1st ed. Switzerland: SPRINGER INTERNATIONAL PU; 2018.

[2] Hunley J. The History of Solid-Propellant Rocketry: What We Do and Do Not Know.35th AIAA, ASME, SAE, ASEE Joint Propulsion Conference and Exhibit [Internet].1999 [cited 13 April 2022]; (35): 1-10. Available from: https://ntrs.nasa.gov/citations/19990047654

[3] Mason B, Roland C. SOLID PROPELLANTS. Rubber Chemistry and Technology [Internet].2019; 92 (1): 1-24. Available from: https://meridian.allenpress.com/rct/article-abstract/92/1/1/431079/SOLID-PROPELLANTS?redirectedFrom=fulltext

[4] Oshima K. Thermal and fluid mechanical problems in space flight. Proceedings of the Indian Academy of Sciences Section C: Engineering Sciences [Internet].1981; 4 (3): 363-380. Available from: https://www.ias.ac.in/article/fulltext/sadh/004/03/0363-0380

[5] Encyclopedia of Physical Science and Technology.3rd ed. https://www.sciencedirect.com/referencework/9780122274107/encyclopedia-of-physical-science-and-technology; 2003.

[6] Davenas A. History of the Development of Solid Rocket Propellant in France. Journal of Propulsion and Power.1995; 11 (2): 285-291.

[7] Rocket propellant-New World Encyclopedia [Internet]. Newworldencyclopedia.org.2022 [cited 13 April 2022]. Available from: https://www.newworldencyclopedia.org/entry/Rocket_propellant

[8] McGowen T. Space Race [Internet]. Goodreads. com.2008 [cited 13 April 2022]. Available from: https://www.goodreads.com/book/show/8984314-space-race

[9] Games A. Balderdash & piffle.2nd ed. ISBN 978-0563493365: BBC Books.

[10] rocket-Liquid-propellant rocket engines [Internet]. Encyclopedia Britannica.2022 [cited 13 April 2022]. Available from: https://www.britannica.com/technology/rocket-jet-propulsion-device-and-vehicle/Liquid-propellant-rocket-engines#ref46959

[11] Sutton, E. P; Biblarz, O. (2010). *Rocket Propulsion Elements*. New York: Wiley. ISBN 9780470080245.

[12] Tsiolkovsky, Konstantin E. (1903), "The Exploration of Cosmic Space by Means of Reaction Devices (Исследованиемировыхпространствреактивнымиприборами) ", The Science Review (in Russian) (5), archived from the original on 19 October 2008, retrieved 22 September 2008

[13] *Zumerchik, John, ed. (2001). Macmillan encyclopedia of energy. New York: Macmillan Reference USA. ISBN 0028650212. OCLC 44774933.*

[14] Merits of liquid propellant Rocket Engines and Applications [Internet]. American Institute of Aeronautics and Astronautics.2022 [cited 13 April 2022]. Available from: https://arc.aiaa.org/doi/pdf/10.2514/5.9781600868870.0005.0022
[15] Space handbook: astronautics and its applications. Solar Energy [Internet].1960; 4 (1): 50. Available from: https://history.nasa.gov/conghand/intro.html
[16] Liquid Propellants [Internet]. NAROM.2022 [cited 13 April 2022]. Available from: https: //www.narom.no/undervisningsressurser/sarepta/rocket-theory/rocket-propellants-2/liquid-propellants/
[17] Rocket Fuel-Drishti IAS [Internet]. Drishti IAS.2022 [cited 13 April 2022]. Available from: https://www.drishtiias.com/daily-updates/daily-news-analysis/rocket-fuel
[18] Page citations and linking [Internet]. TheFreeDictionary. com.2022 [cited 13 April 2022]. Available from: https://acronyms. thefreedictionary.com/_/cite.aspx?url=https%3A%2F%2Facronyms.thefreedictionary.com%2FTHBL&word=THBL&sources=acr
[19] Ball P. New rocket fuel?. Nature.2002; Rocket Fuel drishtiias.com/printpdf/rocket f

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