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Cover Page Footnote

Thank you for the opportunity to submit my article to this journal.

Engine Use In Hybrid Rocket -A Review

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Abstract—Despite all the other rocket motors on the market such as solid and liquid. A historically failed motor was in the market which was handicapped in performance but now with technological development in the previous years, hybrid rocket motor is the most influential talk in the market.
Deeper in the paper we will discuss the hybrid motor focusing on the fuel used in Hybrid rocket engines and the performance depending on the design. Furthermore, this review paper will help us to study the different materials for the betterment of the engine performance. We will also be focusing on the methods required to improve total impulse. Moreover, will be elaborating on the performance of paraffin wax and its material property.

Keywords-Hybrid, Rocket, Engines, Paraffin Wax, Fuel, Impulse

I. INTRODUCTION

A hybrid rocket engine is a combination of both solid and liquid engines. It has the qualities of both solid and liquid engines. It is economical like a solid rocket engine and gives a better technical performance than a Liquid rocket engine. A hybrid rocket engine consists of a solid propellant mostly the fuel and a liquid propellant the oxidizer as shown in fig 1[1]. The best thing about a Hybrid rocket engine is, that if any system failure is there then there will be no explosion. A hybrid rocket engine is more durable as compared to others. Just like a liquid rocket engine, we can shut it down easily. The specific impulse (Isp) of hybrid rocket engines is more than solid rocket engines but less than that of liquid rocket engines. Whereas it is not easy to handle a hybrid rocket engine as compared to a solid rocket engine but as it is not hazardous one should go for the hybrid rocket engine. In addition to that, we will further be outlining the tensile tests for paraffin wax after the mixing of specific additives.

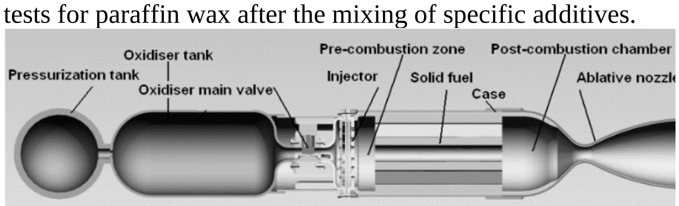

Figure 1. Hybrid rocket motor

II. COMMON FUEL CHOICES FOR HYBRID ROCKET ENGINE

In a hybrid rocket engine, we use solid Propellant as a fuel and liquid propellant as an oxidizer. In a hybrid rocket engine, we need fuel that has a high specific impulse. In this review paper, we will look at the various solid propellant which is used as fuel in a hybrid rocket engine. Paraffin wax can be used in hybrid rocket engines as fuel (in small-scale hybrid rocket engines). Paraffin wax is a mixture of saturated n- and iso-alkanes, naphthene, and alkyl-substituted and naphthene-substituted aromatic compounds. The chemical formula of paraffin is CnH2n+2. One of the main reasons to use paraffin wax is the regression rate.

A. *Paraffin Wax*

The chemical reaction of Paraffin Wax:

Paraffin wax + Oxygen → Carbon dioxide + Water

$C_{25}H_{52} + O_2 \rightarrow CO_2 + H_2O$

For this kind of reaction, we have a combustion reaction.

A combustion reaction is a chemical reaction between combustible material and oxidizer to form oxidized products. Thus creating fire and releasing energy in the form of heat.The balanced reaction for the Paraffin wax is:

$C_{25}H_{52} + 38O_2 = 25CO_2 + 26H_2O$.

Paraffin Wax-based rocket motors tend to replace conventional solid rocket motors on a large scale. Since these motors are non-toxic, non-hazardous, can be controlled during their throttling, and have several other advantages over HTPB/ammonium perchlorate. However, in doing so firstly we will have to understand the tensile properties of the wax for it to be used on a large scale because there is no structural tank for it to be stored and so wax should have the properties to be strongly bonded or hold together during assembly and storage[12].

Pure paraffin wax has maximum tensile strength as near to HTPB rubber which is used as a binder in solid rocket motors. The paraffin wax in the lowest melting point has slightly greater tensile strength than the high melting point wax and a little larger per cent elongation as shown in the following Table 1[12].

TABLE 1.

Paraffin Wax	Additive	Percent purity	Tensile Strength MPa	Percent Elongation
52°–54°C	None	100	1.38	0.8
52°–54°C	Epolene C-15 Wax	99 .5	1.38	0.8
52°–54°C	Epolene C-15 Wax	99	1.38	0.8
52°–54°C	Epolene C-15 Wax	97	1.86	1.6
60°–63°C	None	100	1.03	0.6
60°–63°C	Epolene C-15 Wax	99.5	1.03	0.6
60°–63°C	Epolene C-15 Wax	99	1.24	0.6
60°–63°C	Epolene C-15 Wax	97	1.93	1.1
66 °C	ethylene vinyl acetate 16%/Petroleum resin 5%	79	3.10	
56 °C	Graphite foam		1.30	

Paraffin wax is fundamentally manufactured by the centrifugal force when liquid wax is poured into the mould. This force is used to avoid cracking and voids. However, due to the shrinkage property of wax during its cooling state, the voids are formed so to tackle these voids additives are used during its centrifugal process in the liquid state. Additives further modify the material properties. LDPE is the most popular additive being used and LDPE stands for "Low-Density Polyethylene"[13].

Further in this, I will outline the results for additives used in different quantity-wise: 4% LDPE added to paraffin wax, Pure paraffin wax, and 2% LDPE added to paraffin wax.

The dogbone-shaped test samples were used for the tension tests.

The Instron uniaxial testing machine was used to measure the tensile strength and elongation.The test sample is held between two wedge strips, each attached to a crosshead. The upper crosshead was attached to the vertical columns while the lower head was attached to a screw and an electric motor which caused up-down movements. The experiment was to run two different elongation rates 5.08 mm min–1 or 50.8 cm min–1. However, the 2% LDPE added to paraffin wax and Pure paraffin wax showed positive results after the tests but 4% LDPE added to paraffin wax showed not so good results even after the second test was performed on it.The failed one showed extensive bubble formation. Hence proving the tensile strength and elastic modulus were both greater for the non-bubbled dogbones than the samples that had bubbles as shown in following fig 2.

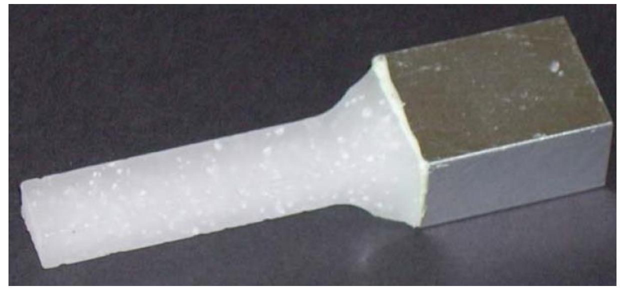

Figure 2. Bubbles on the sample

B. *Total Impulse*

Total impulse is the product of the sum of trust generated and the time interval. The total impulse in rocketing can be explained by how fast the propellant ejected from the back of the rocket. The specific impulse can be calculated from the total impulse. Specific impulse is the total impulse divided by the propellant weight. In this review paper, we studied some of the prototypes of the hybrid rocket in which we got the total impulse as 50 KN [2]. For 50 KN they used nitrous oxide and paraffin wax as a solid fuel. The total impulse depends on which scale we are experimenting. If we want high total impulse then we have to experiment on a large scale in that case we will need more fuel. In another prototype of a hybrid rocket engine in which we used Gaseous oxygen as oxidizer and paraffin wax along with Ultra-High Molecular Weight Polyethylene (UHMWPE), we got a total impulse of around 209s [3]. The SI unit of total impulse is N.s. The more the total impulse more the trust generated and more the efficiency [7].

C. *Pressure in the combustion chamber*

It is observed in the experiment that the pressure in the combustion chamber decreases. It is also explained with the help of a spectrogram and the graph of post and pre-combustion. The solid fuel when mixed with the oxidizer, instability occurs which causes a change in pressure and temperature both in the combustion chamber [2][6]. The pressure and temperature decrease as shown in fig 3 [2].

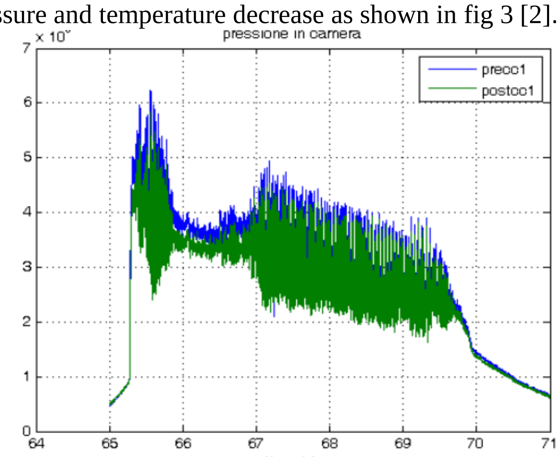

Figure 3. Pre and Post pressure in the combustion chamber

The thrust generated and the pressure in the combustion is discussed in detail by PawełSurmacz and Grzegorz Rarata in Hybrid Rocket Propulsion Development and Application paper[1][8]. They gave a relation between the thrust generated and the pressure in the combustion chamber as shown in fig 4 [11].

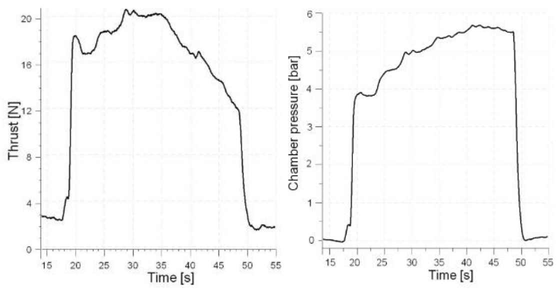

Figure 4. Test results of a hybrid motor test: Thrust (a) and Chamber pressure (b)[1][9]

D. Combustion efficiency before and after post-combustion

As shown in fig. 5[2].The post-combustion is present at the end of the combustion chamber. The post-combustion chamber helps to achieve the highest efficiency of a motor engine. There can be a significant change in the engine performance if post-combustion is not there. To explain the importance of the post-combustion process there is a graph presented by Alberto Bettella in his paper[2].

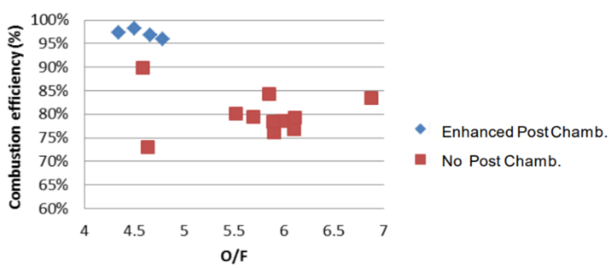

Figure 5. Combustion efficiency

The importance of the post-combustion chamber is explained in this chart. The combustion chamber efficiency can be increased by 15-20 per cent with the post-combustion presence. The O/F ratio is the ratio of oxidizer to fuel mass flow rates.

E. Burn Time

Burn time is the duration for which the rocket engine produces meaningful trust. In a hybrid rocket engine, the burn time is very small. If we want to calculate the burn time mathematically then we can get it by multiplying the volume of the solid fuel by the density of the solid fuel. The prototype that we discussed in this review paper which gave a total impulse of 50KN has a burn time of 3.5s to 5s. The Burn time of hybrid rocket engines will increase with the scale of the rocket. The prototype with a total impulse of 209s gave a burn time of around 18s. the burn time is very less as the effective thrust generates for a very few sec [2][5]. The burning of the motor is shown in fig 6.

Figure 6. Thrust generated

III. MATERIAL USED IN HYBRID ROCKET

The hybrid rocket motor is used to store solid propellant and another one is used to store liquid propellant which is an oxidizer. While selecting the material for a hybrid rocket engine it is very important to understand that we should use a material that can withstand high temperatures. Stainless steel can be best for rocket motors as it can withstand high temperatures. So far we have seen that paraffin wax is the most common solid propellant used in hybrid rocket engines. We put this paraffin wax in a cylindrical motor which can be made of stainless steel. If we are experimenting at a lab level we can use fibre glass, aluminium, and high-tensile stainless steel For the motor. The nozzle that we use in a hybrid rocket engine can be of graphite or copper [2][4]. The following materials as shown in fig 7 [2].

Figure 7. Stainless steel materials

IV. CONCLUSION

In this review, we discussed the tests of the paraffin wax motors that are found to be less elastic than HTPB rubber with a much lower per cent elongation. Also, the use of Paraffin wax motor in future will drastically reduce the cost and cut the toxic gases when burned. The addition of LDPE potentially has the advantage of reducing the number of small voids in the paraffin wax which shows paraffin wax may have the opportunity to be energetic fuel. Furthermore, we showcased the types of fuel and total impulse, and burnt time to maximize the efficient thrust produced.

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REFERENCES

[1] P.Surmacz, G. Errata, Hybrid Rocket Propulsion Development and Application. January 2009.

[2] Alberto Bettella, Nicolas Bellomo, Development of 20 kN hybrid rocket booster. January 2013.

[3] Adam P. Trump our, Hybrid Rocket Engine Research In Support Of Prototype Development & Testing. January 2010.

[4] M. A. Karabeyoglu, Greg Zilliac, Brian J. Cantwell, Shane DeZilwa and Paul Castellucci, "Scale-up Tests of High Regression Rate Liquefying Hybrid Rocket Fuels", AIAA-2003-1162, 41st Aerospace Sciences Meeting and Exhibit, Reno Nevada, January 2003.

[5] Karabeyoglu, M. A., Altman, D., Cantwell, B. J., "Combustion of Liquefying Hybrid Propellants: Part 1, General Theory", Journal Of Propulsion And Power, 2002.

[6] Humble, R.W., Henry, G.N. and Larson, W.J. 1995. Space Propulsion Analysis and Design. McGraw-Hill, New York.

[7] Chiaverini, M.J. and Kuo, K.K. 2007. Fundamentals of Hybrid RocketCombustion and Propulsion. American Institute of Aeronautics and Astronautics, Inc., Reston, VA.

[8] M. C. Ventura: Long Term Storabilityof Hydrogen Peroxide, 41st AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Tucson, AZ, July 10-13, 2005.

[9] E. Wernimont, M.Ventura, G.Garbodenand P. Mullens: Pastand Present Usesof Rocket Grade Hydrogen Peroxide, General Kinetics, LLC Aliso Viejo.

[10] B. Cantwell, A.Karabeyoglu, G.Zilliac: Recent Advancesin Hybrid Propulsion, Stanford University, Department of Aeronautics and Astronautics, 2007.

[11] Carmineicino C., "Acoustics, Vortex Shedding, and Low-Frequency Dynamics Interaction in an Unstable Hybrid Rocket", Journal Of Propulsion And Power November-December 2009.

[12] John D. DeSain, Brian B. Brady, Kelly M. Metzler, Thomas J. Curtiss and Thomas V. AlbrightTensile Tests of Paraffin Wax for Hybrid Rocket Fuel GrainsAEROSPACE REPORT NO. ATR-2009(8268)-1 2008

[13] Karabeyoglu, M. A.; Altman, D.; and Cantwell, B. J., High Regression Rate Hybrid Rocket Propellant, U.S. Patent 6684624, Feb. 4 2004.