Effect of Turbulence Inducer on Regression Rate In Hybrid Rocket Motor Using Two Different Fuels

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Abstract- *Hybrid Rocket Motor is the mixture of the solid and liquid rocket motor. Using wax as a fuel is a method which shows improved regression rate than other conventional fuels. This effort aimed at the enrichment of fuel regression rate by providing turbulence inducers called vortex generators experimentally through which turbulence is generated, where injected gaseous oxygen gets whirled and improve the mixing with fuel resulting in enhanced regression rate. In the present work, a showerhead injector type and cylindrical wax based fuel grain configuration was used. The regression rate behavior of paraffin and bee wax fuel is analyzed at the same injection pressure. Combustion result shows enhancement in fuel regression rate and improved mass consumption rate of the fuel grains. Hence, the addition of vortex generator to the classical hybrid motor set up increase the regression rate of the wax based fuel which in turn increase the thrust of the motor.*

Keywords- Hybrid Rocket motor, vortex generator, turbulence, paraffin wax bee wax and regression rate

I. INTRODUCTION

Hybrid rocket motor is an engine which shares the advantages of solid and liquid engines. The concept has been known and tested for many decades. However, application in early practical systems has been limited. Lately, there is a renewed interest in this type of propulsion, due to its high safety level as well as lower environmental impact(1). Typical hybrid rocket motor is given in the fig.1. Despite their advantages, classic hybrid engines possess a major disadvantage - a low fuel burning rate and, hence low thrust (2). Research has been carried out over the year to find out class of fuel with a higher regression rate than that of conventional hybrid fuels. It was found that members of normal alkaline class of hydrocarbons, which are solid at room temperature for carbon number 14, have low surface tension and viscosity, which include the paraffin waxes and polyethylene waxes (3).

In our research, concept of using vortex generator is employed with this rocket motor to investigate about the possibilities of enhanced regression rate as well as combustion reliability on this new environment. The current hybrid motor is equipped with shower head injector to inject gaseous oxidizer, it is known that swirl injectors are far superior to shower head but because of its simple design and fabrication would be an added advantage (4). It was observed that turbulence would be an added advantage for an effective combustion (5). It can be achieved by placing the Vortex generator ahead of combustion chamber to generate turbulence on injected oxygen from an injector. Through this enhanced regression rate can be achieved from simple shower head injector. The experimental study of combustion was carried out for a different composition (100% paraffin Wax, 100% Bees Wax and 50% paraffin Wax + 50% Bees Wax) of fuel grains at same oxidizer injection pressure and motor burning time. The parameters planned to assess were local regression rate, average regression rate and average mass consumption rate of fuel grain.

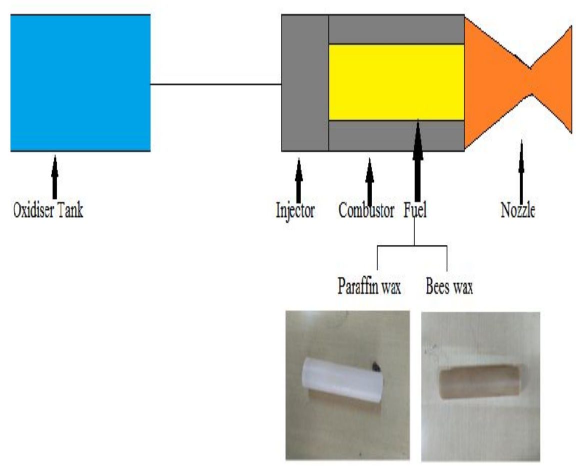

Fig. 1 Schematic representation of hybrid rocket motor

II. EXPERIMENTAL SETUP AND RESEARCH METHODOLOGY

Test facility includes a flanged cylindrical chamber made from mild steel with length 150mm and inner diameter 47mm has been used as the combustion chamber and a conventional shower head injector at one end, and a convergent-divergent nozzle made from graphite inserted in a stainless steel of length 51.50mm and throat diameter 6mm at the other end. The nozzle convergent angle and divergent angles were 45° and 15°, respectively. The fuel grain was processed separately and then cast inside the combustion chamber before firing, Paraffin wax and Bees wax combinations were engaged as a fuel in the current exploration. Triangle vortex generator was used to generate turbulence in the flow which is shown in the Fig. 2. The prepared paraffin wax and Bees wax fuel grains can be seen in Fig.1

Fig. 2 Triangular vortex generator

The pressure regulator in the feed line was adjusted at the desired oxidizer injection pressure during firing. The combustion was initiated by switching on the ignition and the combustion was terminated after a lapse of the prerequisite duration of 8 seconds. The firings of the fuel grains were carried out at three different fuel grain composition with the pressure of 80psi. The grain was removed from the motor after firing and was weighed to determine the mass consumption rate, which may be computed by the difference of the weight before and after firing. The fuel grain was cut along the length at four different points for visual inspection and measurement of the unburned thickness along the length of the fuel grain at 10mm intervals. The local regression rate was determined by measuring the unburned web thickness at each 10mm interval with the help of a micrometer.

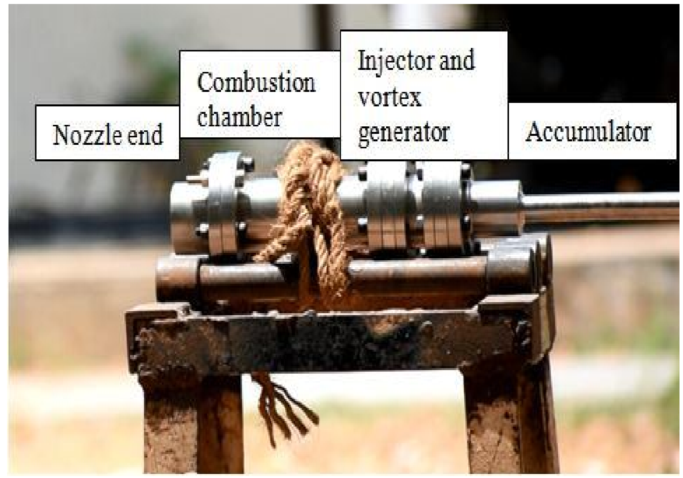

Fig. 3 Overall motor assembly

III. RESULTS AND DISCUSSIONS

In the current investigation series of firings have been carried out on the laboratory scale hybrid rocket motor with or without vortex generators for the different fuel composition of wax based fuels. After conducting series of test firings the injection pressure and firing duration were fixed as 80 psi, 8 seconds respectively. Each firing was recorded using digital single-lens reflex camera for analyzing the nature of exhaust plume of the individual fuel composition. The principally determined variables from the firing were local regression rate, average regression rate of fuel and fuel consumption under the situation of with and without vortex generators.

Initial firing was prepared for 100% Paraffin wax to test out the combustion behavior with and without vortex generator. From the estimation, it shows that substantial influence of turbulence on regression as well as mass consumption rate of fuel grain. Images of the respective firings were exposed below in Fig. 4(a) and 4(b).

Second set of firing was proceed with 100% Bees wax fuel grain, unlike first firing uniform regression rate improvement was seen in the fuel grain and maximum value of regression rate of 0.9987 mm/s was estimated at the injector end's first reference location. For pure beeswax average regression rate with and without VG was found to be 0.70 mm/s and 0.55mm/s respectively. Similarly, For the case of paraffin wax, average regression rate with and without VG was found to be 0.65482 and 0.4733 respectively. The final set of firing was expected to bring out the combustion manners for 50% bees wax 50% paraffin wax fuel grain. Among the all set of firing turbulence influence were only found near the injector end rest of the downstream portions were not literally subjected to turbulence. From the Fig. 4(d), it is clearly indicating the evidence of the turbulence subjected on this fuel grain, nearly three fourth (3/4) of the plume length is visualized in blue color, unlike Fig. 4(b)

Fig. 4(a) Paraffin wax without VG

Fig. 4(b) Paraffin wax with VG

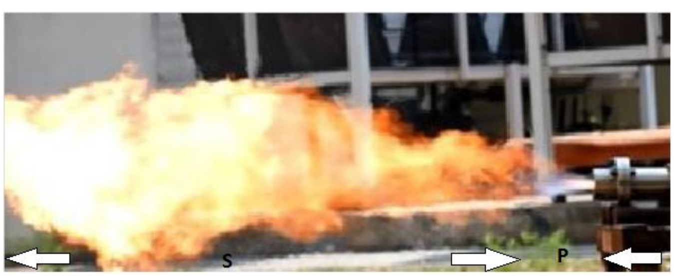

Fig. 4(c) Bees wax with VG

Fig. 4(d) Bees wax with VG

Fig. 4(e) 50% Bees wax and 50% Paraffin wax without VG

Fig. 4(f) 50% Bees wax and 50% Paraffin wax with VG

The above figure shows the firing of paraffin wax, bees wax and 50% bees wax, 50% paraffin wax without and with using vortex generator. The length of primary combustion zone is higher in bees wax with vortex generator than the other types of fuels. In 50% bees wax, 50% paraffin wax with and without vortex generator it is full of secondary combustion with large smoke

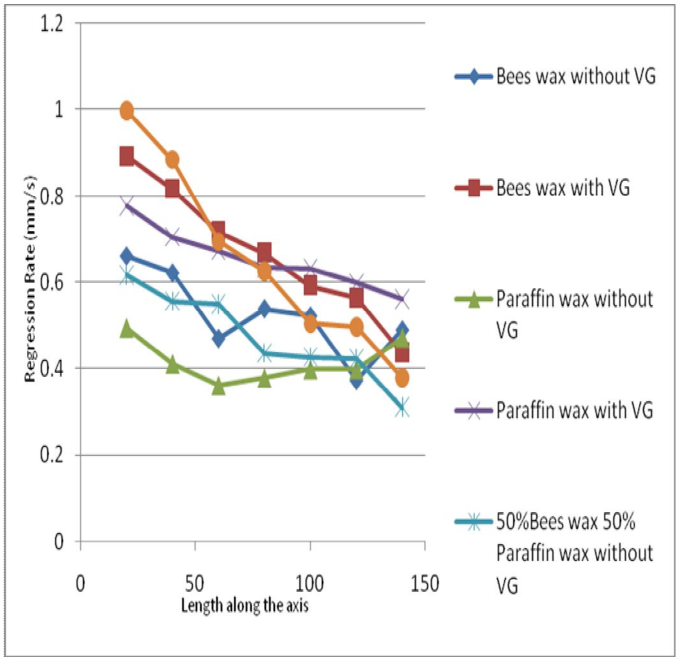

Fig. 5 Local regression rate vs Location

The above figure shows the variation of local regression rate along the length of the paraffin wax, bees wax and 50% bees wax & 50% paraffin wax with and without using vortex generator. The theoretical result show that the regression rate should linearly decreasing from the injector end to the nozzle end (9). The graph has almost linearly decreasing local regression rate only for bees wax using vortex generator. This is because combustion efficiency of fuels mainly depends upon turbulent mixing atmosphere for unburned fuel and oxidizer in the combustion chamber. The local regression rate has been high for paraffin wax using vortex generator than without using vortex generator. Comparing with bees wax, Paraffin wax has low local regression rate initially. For 50% bees wax & 50% paraffin wax with using vortex generator local regression rate has been very high initially but as the length of fuel increased regression rate falls to a lower value.

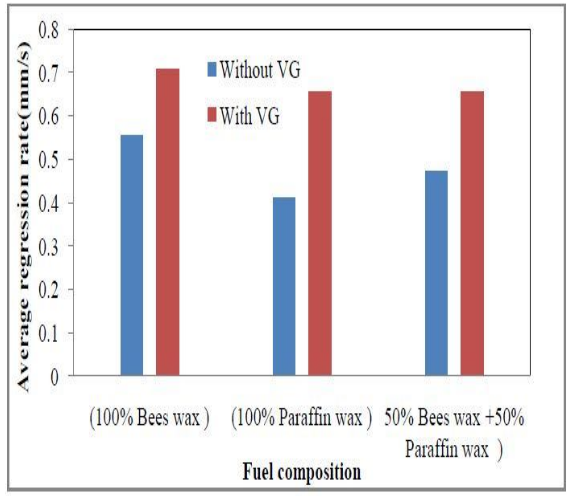

Fig. 6 Average Regression rate for the different fuel composition

Apart from that graph representation, comparison graph also in position to examine the local regression rate and average regression behavior among the fuel compositions. By referring Fig. 5 and 6, it is clear that Bees wax shows the promising improvement on the regression rate than that of other fuels, Even though 50% paraffin wax 50% Bees wax was gaining the high fuel regression rate near the injector end it failed to keep all along the fuel gain. In case of Average regression rate also, Bees wax alone leading in the value for both with and without vortex generator, which can be seen from the Fig. 6

IV. CONCLUSION

A series of paraffin and bees wax-based hybrid rocket fuel was burned experimentally in a laboratory-scale motor. The main conclusions that can be drawn from this work are the enhancement of regression rate was achieved by employing a triangular vortex generator, thereby increasing the thrust of the motor. Comparing bees wax without vortex generator regression rate has increased by 25.8 times than paraffin wax and bees wax with vortex generator regression rate has increased by 7.46 times than paraffin wax. On comparing all the three types of fuel with and without vortex generator, bees wax with vortex generator gives higher regression rate.

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APPENDIX

L = grain length (m)
$\dot{m}$ = mass flow rate (Kg/s)
$\dot{r}$ = local instantaneous fuel regression rate (mm/s)
t = time (burn duration) (sec)
P = Length of Primary Combustion (m)
S = Length of Secondary Combustion (m)