# Pressure Dependence, Propellant Composition, Particle Size & Effect of Catalyst on Burn Rate Study of AN-HTPB based Composite Solid Propellants

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*Abstract*— In the present investigation, an effort has been made to study pressure dependence, propellant composition, particle size and effect of catalyst on the burn rate of AN based composite solid propellant. The variation of oxidizer has been made 70%, 75% and 80% based on earlier experience of the loading of HTPB on the combustion characteristics of AN based composite solid propellants. The particle size of the oxidizer in the present formulation is taken to be 44 µm and 149 µm respectively. The bimodal AN taken with mess size 150 and 300.

***Key words:*** Pressure Dependance; Propellant Composition; Particle Size; Burn Rate; AN; HTPB; $Fe_2O_3$

## I. Introduction

The burning rate of solid propellant depend on various parameters i.e, Chamber pressure, Initial temperature of the propellant, Gas velocity of hot combustion products over the burning surface, Chemical formulation, Oxidizer-binder mixture ratio, Oxidizer particle size (for composite propellants), Total mass flow rate over the burning surface. Some other factors which affect the burning rate are catalysis, sub atmospheric combustion, erosion, radiation, acoustics, electrical fields, and acceleration and surface effects.

### A. *Dependence of Burn Rate on Pressure*

The burning rate dependence on pressure can be expressed as

$$r = a * P_c^{\ n} \qquad \text{(Equation 1)}$$

This is known as De Ville's or St. Robert's law. This happens to be very accurate for all types of propellant and is generally used. In this expression 'n' called the pressure exponent or the combustion index is essentially independent of the initial grain temperature but describes the influence of rocket chamber pressure on burning rate. The other constant 'a' called temperature coefficient is influenced by ambient temperature.

### B. *Dependence of Burn Rate on Propellant Composition*

Propellant composition has a marked influence on the burning rate. All attempts have so far converged in the search of high performance propellants, and they concluded that the burning rate increases with the increase in percentage of oxidizer but only upto a certain limit.

### C. *Dependence of Burn Rate on Particle Size*

The performances of composite propellants have been shown to be directly proportional to the oxidizer content and particle size. The particle size of the oxidizer in the present formulation is taken to be 44 µm and 149 µm respectively.

Renie[13] have investigated the effect of oxidizer size and distribution on non- aluminized composite propellants. They used a new mathematical model called as 'petite ensemble model'. They showed that the oxidizer particle size and distribution have profound influence on burning rate, pressure exponent 'n' and temperature sensitivity. They also showed that the combustion parameters were strongly dependent on coarse-to-fine and the mean diameter of the fine fraction.

### D. *Dependence of Burn Rate on Effects of Catalyst*

The catalytic effect in certain materials has long been noted in solid propellants. A catalyst is a material that increases the reaction rate of a chemical reaction but remains unchanged at the end of the chemical reaction. Ferric oxide ($Fe_2O_3$) is taken as the catalyst in the present formulation.

## II. Experimental

In the present work, it has been attempted to use AN - HTPB composite solid propellant and study their combustion aspects. The different composition were used for experimentally studies with prior experience of the mechanical and combustion behavior of AN - HTPB propellant at the laboratory. The bimodal AP is taken with mess size 150 and 300. The AN are loaded at 70, 75 and 80 percent by weight in HTPB processed with DOA as plasticizer, TDI as curing agent and glycerol.. The basic formulations of the samples consisted of AN – HTPB + catalyst are shown in Table 1.

| S.No | AN (wt%) | HTPB (wt%) | DOA (wt%) | TDI (wt%) | Glycerol (wt%) | $Fe_2O_3$ (wt%) |
|---|---|---|---|---|---|---|
| 1 | 70 | 21.59 | 6.48 | 1.70 | 0.23 | - |
| 2 | 75 | 17.99 | 5.40 | 1.42 | 0.19 | - |
| 3 | 80 | 14.39 | 4.33 | 1.13 | 0.15 | - |
| 4 | 70 | 21.59 | 6.48 | 1.70 | 0.23 | 3 |
| 5 | 75 | 17.99 | 5.40 | 1.42 | 0.19 | 3 |
| 6 | 80 | 14.39 | 4.33 | 1.13 | 0.15 | 3 |

Table 1: Formulation of uncatalyzed & Catalyzed AP-HTPB based Composite Solid Propellants

### A. *Measurement of Burning Rate*

The burning rates of AN-HTPB composite propellants with and without catalysts have been determined at ambient condition and at different pressures, 2.06, 4.76 and 6.89 MPa, using a conventional strand burner. Nitrogen gas has been used to pressurize the bomb. The dial type pressure gauges have been used to record incoming pressure and pressures in bomb and line. A surge tank has been provided in the set- up to ensure that a strict pressure level is maintained in the bomb. This has been shown clearly in figure 1 and figure 2.

The propellant strands, having two fine drilled holes at a distance of 5 cm to position the fuse wires, were installed in the bomb and igniter wire was suitably placed at apex of the strand. The cap, with the provision for electrical connections in it was tightened on to the bomb. The bomb was then pressurized with nitrogen gas to required pressure level. The necessary electrical connections were made and the strand was ignited to record time with the help of an electrical timer. Similar procedure has been followed for each strand. The burning rates were then determined from the time elapsed between the two fuse wires.

Fig. 1: High Pressure Strand Burner Setup

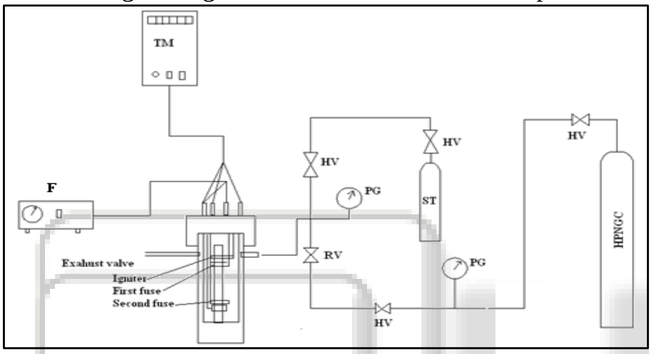


Fig. 2: Line Diagram of High Pressure Strand Burner

## III. RESULTS & DISCUSSION

### *A. Burning Rate Studies of AN-HTPB Composite Solid Propellants*

At the same pressure variation when the experiment is taken out with ammonium nitrate in place of ammonium perchlorate, it is found that none of the propellants burn satisfactorily at 2.0685 MPa nitrogen pressure in the strand burner. Hence, these data are not considered in the present analysis. In open atmosphere, all the propellants burn when ignited with the help of an ignition device. Also, 70% AN - HTPB based composite solid propellants with and without catalyst shows no effect of burning at high pressure upto 6.895 MPa. The burning rate of the propellant is presented in Table 6 and 7 shows similar results for all the compositions with ± 0.3 variation upto 6.895 MPa. The burning in open atmosphere may be attributed to the participation of atmospheric oxygen in the combustion processes of the propellants. At atmospheric condition it leaves carbon skeleton after completion of burning with huge smoke. Ammonium nitrate is more sensitive than the Ammonium perchlorate as it absorb moisture, if it is kept in open space and very difficult to remove moisture easily from it. This gives the reason for its poor performance and it results negative values of temperature coefficient shown in figure 4. It is observed that incorporation of catalyst increases the burning rate of AN - HTPB propellant at all pressures. However increases in burning rate due to addition of catalyst depends on the nature of catalyst incorporated. A comparison of burn rate of AN-HTPB composite solid propellant with variation in pressure is shown in figure 4.

| Types of Propellant | Burning Rate ( mm sec$^{-1}$) Pressure (MPa) 0.101 4.760 2.068 6.895 | | | | a | n |
|---|---|---|---|---|---|---|
| 70% AN - HTPB | 0.167 | - | - | - | - | - |
| 70% AN - HTPB with 3% $Fe_2O_3$ | 0.187 | - | - | - | - | - |
| 75% AN - HTPB | 0.196 | - | 1.88 | 2.428 | 0.750 | 0.588 |
| 75% AN - HTPB with 3% $Fe_2O_3$ | 0.232 | - | 2.062 | 2.690 | 0.849 | 0.568 |
| 80% AN - HTPB | 0.238 | - | 2.061 | 2.365 | 0.871 | 0.551 |
| 80% AN - HTPB with 3% $Fe_2O_3$ | 0.416 | - | 2.257 | 2.481 | 1.212 | 0.398 |

Table 2: Burning rate of Uncatalyzed and Catalyzed AN-HTPB based Composite Solid Propellants at Different Pressures

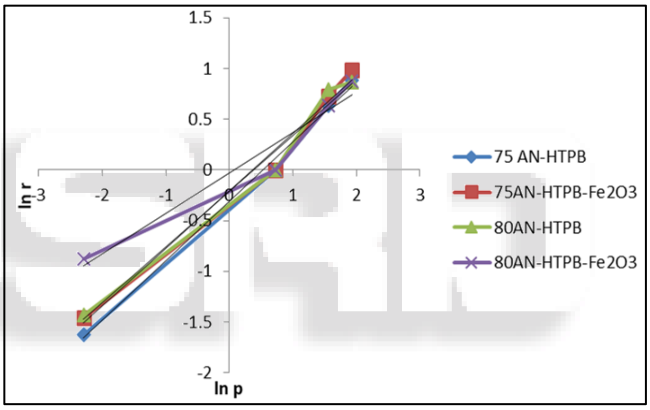


Fig. 3: Comparison of Burning Rate 70, 75 & 80% of AN-HTPB Composite Solid Propellant with Catalyst

| Types of Propellant | ln r ln p -2.2920 0.7265 1.560 1.9307 | | | | ln a | n |
|---|---|---|---|---|---|---|
| 70% AN - HTPB | 0.167 | - | - | - | - | - |
| 70% AN - HTPB with 3% $Fe_2O_3$ | 0.187 | - | - | - | - | - |
| 75% AN - HTPB | 0.196 | - | 1.88 | 2.428 | 0.750 | 0.588 |
| 75% AN - HTPB with 3% $Fe_2O_3$ | 0.232 | - | 2.062 | 2.690 | 0.849 | 0.568 |
| 80% AN - HTPB | 0.238 | - | 2.061 | 2.365 | 0.871 | 0.551 |
| 80% AN - HTPB with 3% $Fe_2O_3$ | 0.416 | - | 2.257 | 2.481 | 1.212 | 0.398 |

Table 3: Pressure Dependence of Burning rate of AN - HTPB based Composite Solid Propellants at different Pressure

## IV. Conclusions

AN - HTPB based composite solid propellants are both hard to ignite and difficult to sustain combustion at ambient as well as high pressures. However, once ignited they burn smoothly at pressure around 4.765 Mpa. Finally, it is observed that the burning rate of AN - HTPB comes in lower side and the pressure index at higher side, indicate poor performance of the propellants.

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