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SOLID PROPELLANT BURN RATE ENHANCEMENTS WITH VARIOUS GRAIN CONFIGURATIONS

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ABSTRACT

Solid propellants are one of those rocket motor fuels which are widely used in gun and rocket propulsion applications. They are energetic and produce high temperature gaseous products on combustion. The energy produced by a unit volume of a propellant is called its energy density. The high material density of solid propellants lead to high energy density needed for producing the required propulsive forces. A solid propellant consists of several chemical ingredients such as oxidizer, fuel, binder, plasticizer, curing agent, stabilizer and cross-linking agents. Different grain sizes and different propellant grain configurations are available for improving the impulse of solid propellant rocket motors.

Chemical ingredients and their proportions results in different physical, chemical properties, internal ballistic properties, mechanical, thermal, storage, stability properties, hazard properties and combustion properties. Better selection criterion of propellant is a challenge at present state of art for the solid rocket motor designer that enhances the mission performance. Sometimes solid propellants may burn suddenly and some moments it may fail due to lack of oxidizer and other ingredients. Most of the composite propellant compositions contain solid loading up to 86%. The main solid ingredients of composite propellant are ammonium perchlorate and aluminium powder. Therefore it is must characterize these to improve process ability and quality of composite propellant. Effect of oxidizer percentage in composite ballistic properties and parameters are well determined in literature. In the present study oxidizer percentage, burn rate, catalyst and oxidizer to fuel ratio influences the property characterization are discussed. The data obtained from the experiments will be help full to evaluate some of the propellant characteristics mentioned as challenges.

Strand burner test is conducted to determine the propellant burning rate. This approach is based on strand burner pressure–time history that is related to the temperature change due to exothermic reaction heating of chamber gases and gas addition to the chamber by propellant combustion products. Calculated burning rates were compared with the experimental wire-break time results provided simultaneously and with the propellant manufacturer's results, when available.

3 Different grain configurations have been modeled and tested for burn rate measurements. The comparisons reveal that the approach has merit and that more accurate pressure determination coupled with additional thermo chemical information and strand burner gas temperature measurements has the potential to make this approach a viable technique and one that can be applied in conjunction with other burning rate measurements. The proposed method is similar to a well-developed technique which is commonly applied to ballistic powders but with adjustments for the differences in geometry, pressure, and time of event.

Keywords:
Solid Propellant, Burn rate, Coefficient Of Pressure, Ammonium Perchlorate, Hydroxyl Terminated Poly Butadiene, Ammonium Nitrite, Total Pressure Loss Coefficient

1. INTRODUCTION

1.1 LITERATURE SURVEY:

Solid propellants are widely used in modern rockets and missiles. The history of rockets could be traced to the discovery of gun powder over a thousand years ago. The technology could be perfected only by the latter half of 20th century. The failures of gun powder in the rockets largely due to the unknown consolidating technique of the powder composition. The emergency of large solid propellant motors had to wait the dawn of polymer science and technology.

Specific syntheses of functionally terminated polymer having cross linking capability led to the emergence of casting technology of solid composite propellants. This review describes the various polymeric fuel binder systems used or considered for used in the solid propellants. It includes a brief background, advantages, and shortcoming of the various system used binders and a critical survey of the advanced polymer envisaged for future usage. Special emphasis has been laid on recently synthesized polymer having N-N bonds in their structures, and on the feasibility of developing smokeless propellants based on ammonium nitrate. [1]

In composite solid propellant the oxidizer and binder play a significant role in controlling the ignition and combustion. It is not known precisely whether the binder degradation behavior or oxidizer decomposition behavior would control the ignition of the propellant. Sufficient information is not available on the ignition of the composite propellant as a function of oxidizer concentration [1].

They are two types of solid propellants [2], which are differentiated by the condition in which their ingredients are connected in homogeneous propellants the oxidizer and fuels are chemically linked and form a single chemical structure. These propellants are physically homogeneous. In heterogeneous propellants the oxidizer and fuel are physically mixed but not have chemical bond s between them these propellants. These propellants are physically heterogeneous

Heterogeneous propellants have a non-uniform physical structure. The fuels usually have a polymeric hydrocarbon structure, such as hydroxyl terminated poly butadiene. The fuel has a dual function: to produce energy when burned with oxidizer –rich species. To bind the oxidizer particles to gather to form a specified propellant grain shape [2].

A solid propellant consists of several different types of ingredients. Each of these ingredients serves a specific function. The most common ingredients are oxidizer, fuels binder, plasticizer and burn rate catalyst etc. [2]

AP- based composite propellants usually produce white smoke on combustion. This is because one of the combustion products HCL nucleates the condensation of moisture in the atmosphere, resulting into fag or mist. Such smoke is not produced if AN used, but it lowers the performance due to reduction in the specific impulse.

AP-HTPB is the most commonly used combination because HTPB is considered to be a superior binder to achieve high combustion performance as well as desired propellant physical and mechanical properties [5].

Powdered spherical aluminium is the most common. It consist of a small spherical particles and is used in a wide variety of composite and composite – modified double base propellant formulation, usually consisting 14 to 20% of the propellant by weight. Small aluminium particles can burn in air and this powder is mildly toxic if inhaled. During rocket combustion this fuel is oxidized into aluminium oxide [6].

HTPB propellant slurry shows a time-dependent flow pattern. The rheological parameters depend on the mixing parameters like mixer blade speed and mixing cycle time to some extent. A speed of 25 rpm seems to be the optimum, beyond which, too much shear could shatter the AP particles. Continuous mixing further leads to breakage of AP particles, there by effect the course to fine AP ratio [3].

Composite solid propellant are heterogeneous mixture consisting of a large proportions of oxidizer, usually ammonium perchlorate and a fuel-cum-binder, generally hydroxyl-terminated poly butadiene or Carboxyl-terminated poly butadiene. In addition, they contain curing agents, plasticizers and bonding agents for improving their mechanical properties, and metallic fuel additives and burning rate modifier for improving specific impulse and burn rate, respectively [1].

AP –poly vinyl chloride propellant was made as follow. 20g of PVC powder was taken in a beaker and to it 20g of dry Di Butyl phthalate was added in little amounts with continuous sting so that a thick paste is obtained. AP was mixed with this paste and cast in small diameter glass moulds which were subsequently cured at 373k for 8 hr. followed by heating at 303k for 5 hr. [1]

Analytical models of the burning rate and the combustion process exist and are useful for preliminary design and for extending actual test data; for detail designs and for evaluation of new of modified propellants, engineers need some actual test data. Burning rate data are usually obtained in three ways [6]—namely, form testing by;

1 .Strand stand burners often called Crawford burners
2. Small – scale ballistic evaluation motors
3. Full – scale motors with good instrumentation.

1.2 SOLID PROPELLANT:

A solid propellant is a solid state substance that contains both oxidizer and fuel and is able to burn in the absence of ambient air. Solid propellants usually generate a large number of gaseous molecules at high temperatures (T_f=2,300–3,800 K) during combustion. Condensed phase species are produced, especially from metalized solid propellants. High temperature combustion products are used mainly for propulsion and gas generation purposes.

Solid propellants widely used in gun and rocket propulsion applications. They are very energetic and produce high temperature gaseous products on combustion. The energy produced by a unit volume of a propellant is called its energy density. The high material density of solid propellants leads to high energy density needed for producing the required propulsive force. Propellants on board a rocket are burned in a controlled way (deflagration) to produce the desired thrust.

2. SOLID PROPELLANT CLASSIFICATION

2.1 CLASSIFICATION

There are two types of solid propellants, which are differentiated by the condition in which their ingredients are connected:

1. In *homogeneous propellants*, the oxidizer and fuel are chemically linked and form a single chemical structure. These propellants are physically homogeneous.
2. In *heterogeneous propellants*, the oxidizer and fuel are physically mixed but do not have chemical bonds between them. These propellants are physically heterogeneous.

2.2 Grain Configurations:

We have different grain configuration used in the solid propellant. They are

1. Solid cylindrical grain configuration
2. Hollow cylindrical grain configuration
3. Star shape grain configuration
4. Multi Hollow cylindrical grain configuration
5. Dog Bone grain configuration
6. Other grain configuration

Propellants are processed into a similar basic geometric form, referred to as a propellant *grain*. As a rule, propellant grains are cylindrical in shape to fit neatly into a rocket motor in order to maximize *volumetric efficiency*. The grain may consist of a single cylindrical *segment*, or may contain many segments. Usually, a central *core* that extends the full length of the grain is introduced, in order to increase the propellant surface area initially exposed to combustion.

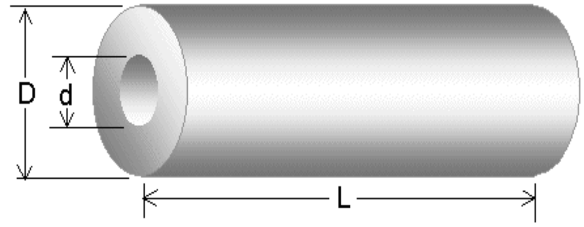

Figure-2.1: Hollow cylindrical grain

The core may have a wide variety of cross-sections such as circular, star, cross, dog-bone, wagon-wheel, etc., however, for amateur motors, the most common shape is circular. The core shape has a profound influence on the shape of the thrust-time profile as shown above figure.

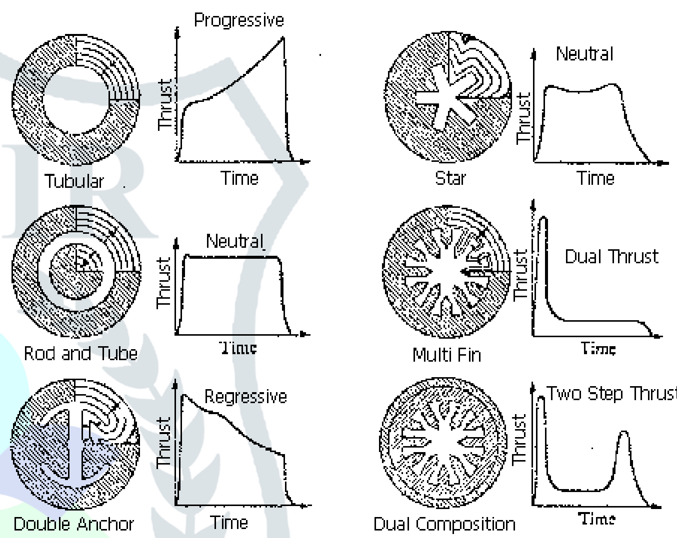

Fig.2.2 Different Grain Configuration

The core shape influences the thrust-time curve? The thrust (and chamber pressure) that a rocket motor generates is proportional to the burning area at any particular instant in time. This is referred to as the *instantaneous burning area*. The burning surface at any point recedes in the direction normal (perpendicular) to the surface at that point, the result being a relationship between burning surface and web distance burned that depends almost entirely on the *grain initial shape* and restricted (inhibited) boundaries. This important concept is illustrated in Figure 3, where the contour lines represent the core shape at successive moments in time during the burn. Notice that the shape of the thrust-time curve changes, with the vertical lines corresponding the same successive moments during the burn. As can be seen, the star grain provides an approximately *neutral* burn, as the surface area remains fairly constant throughout the burn duration. A neutral burn is usually desirable because it provides for greater efficiency in delivery of total impulse, as a nozzle operates most efficiently at a constant chamber pressure.

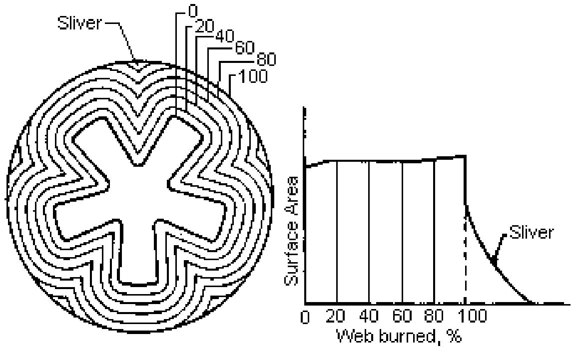

Fig.2.3 Star Configuration

It is important to recognize that the burning area of a propellant grain is a key parameter in determining the performance of a rocket motor. The primary function of a propellant grain is to produce combustion products at a prescribed flow rate defined by:

$$\dot{m}_g = A_b \rho_p r \qquad \text{eq-1}$$

Where ρ_p is the propellant mass density, A_b is the burning area, and r is the propellant burn rate. A complete discussion on burn rate is provided in the Propellant Burn Rate. The total burning area consists of all propellant surfaces that are exposed to combustion (and thus not inhibited from burning by some means). The grain burning area is dependent upon:

- Grain geometry, as described above
- Use of inhibitors

An *inhibitor* is a material or coating that is sufficiently heat resistant such that any propellant surfaces protected by the inhibitor do not combust during the entire operating duration of the motor. Inhibitors for amateur experimental motors are typically paper or cardboard, or a coating such as polyester or epoxy resin.
The design of a motor, we are most interested in the maximum burning area, since it is this area that determines the maximum chamber pressure that the motor will experience. The maximum chamber pressure is used to size the motor casing. For a completely unrestricted-burning grain (e.g. A-100, B-200 & C-400 motors), all surfaces are exposed to the heated gases and thus burning proceeds from all surfaces commencing at the beginning of the burn. A "BATES" grain, which is multiple-segment, hollow cylindrical grain that is case bonded or otherwise has the external surface inhibited, the initial burning surface is that area of the *core and segment ends*. The Kappa rocket motor utilizes such a grain configuration, with a total of four segments.

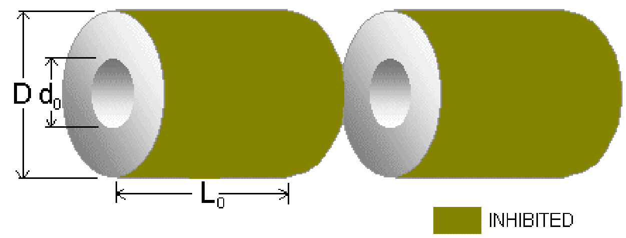

Fig 2.4: Solid Propellant Catridge

Length-to-Diameter ratio is the *grain overall length* in relation to the grain *outer diameter*. This parameter is very significant in motor design, as larger L/D values tend to result in greater erosive burning effects (including negative erosive burning). High L/D values tend to generate high mass flow rate differentials along the grain length, and may be best served with a *tapered* core or *stepped* core diameters (largest nearer the nozzle).

2.5 PROPELLANT CHARECTERISTICS:

The propellant selection is critical to rocket motor design. The desirable propellant characteristics are listed below and are discussed again in other parts of this book. The requirements for any particular motor will influence the priorities of these characteristics:

1. High performance or high specific impulse; really this means high gas temperature and /or low molecular mass.
2. Predictable, reproducible, and initially adjustable burning rate to fit the need of the grain design and the thrust-time requirement.
3. For minimum variation in thrust or chamber pressure, the pressure or burning rate exponent and the temperature coefficient should be small.
4. Adequate physical properties (including bond strength) over the intended operating temperature range.
5. High density(allows a small – volume motor)
6. Predictable, reproducible ignition qualities (such as reasonable ignition over pressure).
7. Good aging characteristics and long life. Aging and life predictions depend on the propellant's chemical and physical properties, the cumulative damage criteria with load cycling and thermal cycling. And actual tests on propellant samples and test data from failed motors
8. Low absorption of moisture, which often cause chemical deterioration.
9. Simple, reproducible, safe, low cost, controllable, and low hazard manufacturing.
10. Guaranteed availability of all raw material and purchased components over the production and operating life of the propellant, and good control over undesirable impurities.
11. Low technical risk, such as a favorable history of prior application.

12. Relative insensitivity to certain energy stimuli described in the next section.
13. Non-toxic exhausts gases
14. Not prone to combustion instability.

Some of these desirable characteristics will apply also to all material and purchased components use in the solid motors, such as the igniter, insulator, case, or safe and arm device. Several of these characteristics are sometimes in conflict twitch each other. For example, increasing the physical strength will reduce the performance and density. So a modification of these characteristics cans often cause changes in several of the others

3 SOLID PROPELLANT INGREDIENTS

TYPICAL INGREDIENTS OF COMPOSITE SOLID PROPELLANTS:

3.1 OXIDIZER

The earliest energetic material referred to by name is "Greek Fire". It was actually developed by the Byzantines of Constant in around the 7" century A.D. and consisted of a petroleum distillate, thickened by dissolving resinous and other combustible materials. Its exact composition is unknown. The development of explosives began with the formulation and use of black powder, which is also known as gunpowder in about the middle of the thirteenth century [',']. In 220 BC, Chinese alchemists accidentally made black powder while separating gold from silver. Black powder was introduced in 14th century by Roger Bacon and in 1320 Berthold Schwartz made black powder and studied its properties. The fuel is a powdered mixture of charcoal and sulphur, which is mixed with potassium nitrate (KN, KN083) oxidizer. At the end of the 181h century and at the beginning of the 191h century the composition became more or less standardised in composition.

Later in the nineteenth century the nitration of many compounds to produce high-energy explosives were realized. Research on explosives greatly intensified during World War ll. Much of the interest in the early part of the 191h century was in the effects of nitration of relatively common materials, such as silk, wool, resins, wood and cotton etc. provides a reference guide to the chemical formulas and structures of some of the more common explosives are in use now. There has been enormous growth in the explosives field in the latter half of the twentieth century with the advent of modern electronic instrumentation, characterization techniques, c:omputational analysis etc.,

Potassium nitrate has an orthorhombic crystal structure at room temperature, which transforms to a trigonal system at 129 °C. Upon heating to temperatures between 550 and 790 °C under an oxygen atmosphere, it loses oxygen and reaches a temperature dependent equilibrium with potassium nitrite.[13]

$$2\ KNO_3 \rightarrow 2\ KNO_2 + O_2$$

Potassium nitrate is moderately soluble in water, but its solubility increases with temperature. The aqueous solution is almost neutral, exhibiting pH 6.2 at 14 °C for a 10% solution of commercial powder. It is not very hygroscopic, absorbing about 0.03% water in 80% relative humidity over 50 days. It is insoluble in alcohol and is not poisonous; it can react explosively with reducing agents, but it is not explosive on its own.

Potassium nitrate can be made by combining ammonium nitrate and potassium hydroxide.

$$NH_4NO_3\ (aq) + KOH\ (aq) \rightarrow NH_3\ (g) + KNO_3\ (aq) + H_2O\ (l)$$

An alternative way of producing potassium nitrate without a by-product of ammonia is to combine ammonium nitrate and potassium chloride, easily obtained as a sodium- free salt substitute.

$$NH_4NO_3\ (aq) + KCl\ (aq) \rightarrow NH_4Cl\ (aq) + KNO_3\ (aq)$$

Potassium nitrate can also be produced by neutralizing nitric acid with potassium hydroxide. This reaction is highly exothermic.

$$KOH\ (aq) + HNO_3 \rightarrow KNO_3\ (aq) + H_2O\ (l)$$

On industrial scale it is prepared by the double displacement reaction between sodium nitrate and potassium chloride.

$$NaNO_3\ (aq) + KCl\ (aq) \rightarrow NaCl\ (aq) + KNO_3\ (aq)$$

TABLE 3.1 Properties of Several Solid Oxidizers

Oxidizer	Molecular Formula	Melting/ Decomposition Temperature (K)	ΔH_f^o (kJ/mol)	Density (Kg/m^3)	Oxygen Balance, %
AN	NH_4NO_3	443	−365.04	1720	20.0
AP	NH_4ClO_4	403	−296.00	1950	34.0
HP_2^*	$N_2H_6(ClO_4)_2$	443	−293.30	2200	41.0
HP^*	$N_2H_5\ ClO_4$	443	−177.80	1940	24.0
ADN	$NH_4N(NO_2)_2$	363	−150.60	1820	25.8
HNF	$N_2H_5C(NO_2)_3$	395	−72.00	1870−1930†	13.1
NP^*	NO_2ClO_4	393	37.10	2220	66.0
RDX	$C_3H_6N_6O_6$	477	70.63	1820	−21.6
HMX	$C_4H_8N_8O_8$	548	74.88	1960	−21.6

3.2 FUELS

Fuels are a material that is burned to produce heat. This section discusses solid fuels. Powdered spherical aluminium is the most common. It consist of small spherical and is used in a wide variety of composite and composite modified double base formulation usually consist of 14 to 20 % of the propellant by weight.

Boron is a high energy fuel that is lighter than aluminium and high melting point (2304). It is difficult to burn with high efficiency in the combustion chambers of reasonable length. However it can be oxidized at reasonable efficiency if the boron particles size is very small. Boron

is used advantageously as a propellant in combination rocket air burning engines where there is adequate combustion volume and oxygen from the air.
Beryllium burns much more easily than boron and improves the specific impulse of a solid propellant motor. Usually by about 15 sec but it and oxide are highly toxic powders absorbed by animals and humans when inhaled.

The technology with composite propellants using powdered beryllium fuel has been experimentally proven, but it's severing to toxic makes its application unlikely. Theoretically, both aluminium hydride and beryllium hydride are attractive fuels because of their high heat release and gas volume contribution. Specific impulse gains are 10 and 15 sec for AL2H3and 25 to 30 sec for BeH2. Both are difficult to manufacture and both deteriorate chemically during storage.

3.3 BINDERS

Binders are provides structural glue or matrix in which solid granular ingredients are held to gather in heterogeneous propellants. The binder must be in liquid form during the preliminary phase of the preparation of the intimate mixture of oxidizer and fuel ingredients, although its elements must have sufficiently low volatility characteristics to withstand the high vacuum used during the mixing of the slurry and the casting of the propellant into a particular grain shape. It must be chemically compatible with the oxidizer, which means that it will not cause even a slight temperature increase that may result in an exothermic reaction leading to any unwanted auto ignition of the propellant. It must be capable of accepting very high solid loading ratios (up to 80% in volume). The mixing operation must remain feasible, and the resulting slurry must be easily cast into the rocket motor case with moulding devices of shapes that are often complex and include some very narrow regions. The mechanical properties of the propellant depend strongly on the selected binder.

The binder raw materials are liquid prepolymers or monomers. After they are mixed with the solid ingredients, cast, and cured, they form a hard rubberlike material that constitutes the propellant grain. In short, a prepolymer is a molecule formed by the repetition (in several orders of magnitudes) of a monomer form (butadiene, polypropylene oxide, etc.), generally ending with reactive functions (telechelic polymers). Binders inherit their essential properties from the prepolymers. These properties can be derived from the nature of the polymeric chain or the properties of the functional group at its ends. The molecular structure of polyether prepolymer is:

H-(O-CH(CH3)-CH2)n-O-CH2-CH(CH3)-O-(CH2-CH(CH3)-O)n-H n = 17

3.7 OTHER ADDITIVES

These are liquid or solid products added in small quantities (a few %) of the binder. Their function is to modify the characteristics of the propellant. Burning rate modifiers are used to modify the propellant burning rate and to adjust the pressure exponent "n" of the burning rate pressure curve in the pressure zone where the propellant grain will be operating. Catalysts are often necessary to reduce the curing time of the propellant. They have a significant impact on the mechanical properties by facilitating some favorable reactions, thereby giving direction to the formation of the polymer network. They are usually salts of transition metals. Examples include dibutyltin dilaurate, lead octoate, iron acetylacetonate, lead chromate etc.,

1) Stabilizer : For increasing chemical stability of composite solid propellant
2) Bonding agent : Used to increase the adherence of each oxidizer particle to the binder
3) Anti aging agent: Used to prevent deterioration of the propellant physical properties with time.
4) Opacifier: Used to make the propellant less translucent so that in depth radiation absorption is avoided.
5) Flames suppressant: For suppressing the flame luminosity.
6) Combustion instability suppressant: For reducing the burning rate sensitivity to pressure fluctuations.

4. Burn Rate

Propellant burning rate is influenced by certain factors, the most significant being:

1. Combustion chamber pressure
2. Initial temperature of the propellant grain
3. Velocity of the combustion gases flowing parallel to the burning surface
4. Local static pressure
5. Motor acceleration and spin

Burn rate is profoundly affected by chamber pressure. For example, KNSU has a burning rateof 3.8 mm/sec. at 1 atmosphere. However, at 68 atmospheres (1000 psi), the burn rate is about 15 mm/sec., a four-fold increase. The usual representation of the pressure dependence on burn rate is the Saint Robert's Law (a.k.a. Vieille's Law

$$\mathbf{r = r_o + a\,Pc^{\,n}} \qquad \textbf{eq-2}$$

Where *r* is the burn rate, r_o is a constant (usually taken as zero), *a* is the burn rate coefficient, and *n* is the pressure exponent. The values of *a* and *n* are determined empirically for a particular propellant formulation, and *cannot* be theoretically predicted. Various means may be employed to determine these parameters, such as a

Strand Burner or Ballistic Evaluation Motor (BEM). It is important to realize that a single set of *a*, *n* values are typically valid over a distinct pressure range. More than one set may be necessary to accurately represent the full pressure regime of interest, as illustrated in Figure 4.1

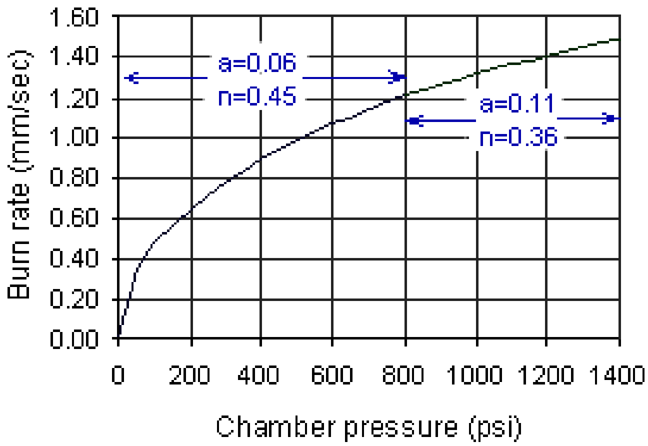

Fig. 4.1 Graph between Burn Rate and Chamber Pressure

If the value of the exponent is close to zero, the burning rate is largely insensitive to pressure, and unstable combustion may result. For these reasons, the pressure exponent for a practical propellant should have a value between 0.3 and 0.6 in the regime of the motor steady-state operating condition.

Temperature affects the rate of chemical reactions and thus the *initial* temperature of the propellant grain influences burning rate. If a particular propellant shows significant sensitivity to initial grain temperature, operation at temperature extremes will affect the time-thrust profile of the motor. This is a factor to consider for winter launches, for example, when the grain temperature may be 20 or more degrees (C.) lower than "normal" launch conditions. Both the KNDX & KNSB Propellants seem to show minor sensitivity to temperature over the range of 0°C to 40°C.

For most propellants, certain levels of local combustion gas velocity (or mass flux) flowing parallel to the burning surface leads to an increased burning rate. This "augmentation" of burn rate is referred to as *erosive burning*, with the extent varying with propellant type and chamber pressure. The mechanism of increased convective heat transfer to the propellant surface due to turbulence is most likely responsible for this augmentation. For many propellants a *threshold* flow velocity exists. Below this flow level, either no augmentation occurs, or a decrease in burn rate is experienced (negative erosive burning). This isillustrated in Figure 4.2

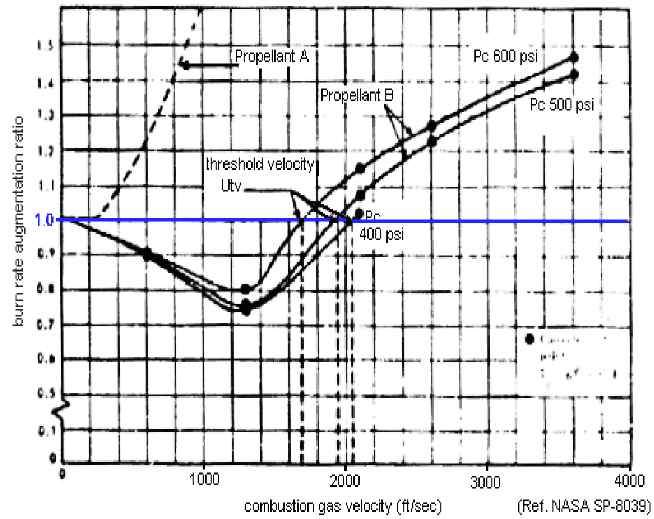

Fig. 4.2 Erosive Burning Phenomena

The burn rate of most propellants is strongly influenced by the oxidizer/fuel ratio (O/F). A compilation of strand test data conducted at ambient pressure for various O/F ratios for the KNDX and KNSU propellants is given in Fig 4.3

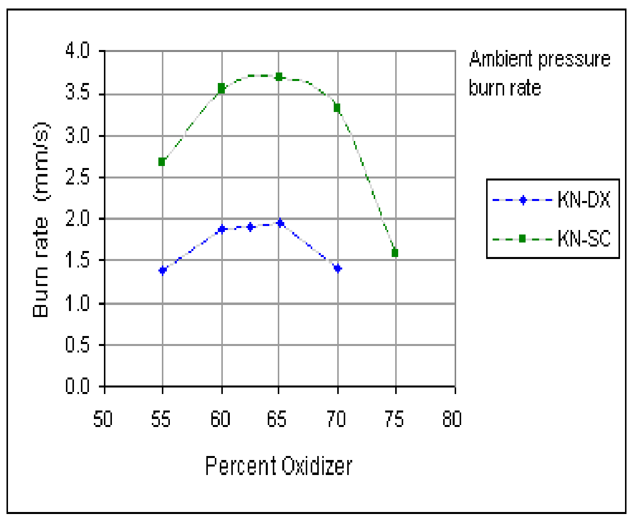

Fig 4.3: Burn rate as a function of Oxidizer to Fuel ratio.

Unfortunately, modifying the burn rate by this means is quite restrictive, as the performance of the propellant, as well as mechanical properties, are also greatly affected by the O/F ratio.

4.2 BURN RATE MEASUREMENT

Burn rate data are usually obtained in three ways:

1. Standard strand burners often called Crawford burner
2. Small scale ballistic evaluation motors
3. Full scale motor with good instrumentation

4.2.1 STANDARD STRAND BURNER

A strand burner is an apparatus that provides burning rate measurements of a solid rocket propellant at elevated pressure. It was used to evaluate new propellant formulations and ensuring quality control for a large propellant production, due to its low cost, simplicity and ability to produce good results in a short time period compared to sub-scale and full scale motor (Fry, 2001). For burning rate measurement, the length of the strand is the importance parameter to be measured, but the size and shape of the strand is less significant. Actually, there were no specific lengths, size or shape for a strand in measuring burning rate. Donald et all reported that, the lengths of propellant strand did not have a significant effect on burning rates. While Matthew et all reported that sample size did not have a large affect on burning rates except for the smallest size tested, 3.2 mm square) used the propellant strand which have circular cross-sectional area while several researcher applied square shape. Strand surface usually burning inhibited with an external coating such as cured HTPB ,vinyl resin solution, bituminous compound (Donald Chiu, 1984) or water based acrylic paint to protect from the heat of combustion and ensure the burning only occur in one dimensional or 'cigarette type'. Commonly, a strand burner has a mounting stand to mount the strand either horizontally. It also equipped with ignition and timing circuit used nickel-chrome wire as an ignition wire. For the timing wire, used in order to simulate the condition of high pressure in a chamber of a rocket motor, inert gas such as helium, carbon dioxide, argon or nitrogen is used to pressurize the strand burner reported that, there are no significant different in the burning rate resulted when applying these gases used the high chamber pressure ranging from 40 atm to 360 atm for burning rate test. However, there were also some studies used low chamber pressures (Holmes, 1989; M. Tanaka, 2000). The information from low-pressure combustion commonly used to optimize a base bleed-propellant design for high-altitude projectile). The previous studies showed that, varying chamber pressures will give different burning rate. The objective of this work is to determine the effect of chamber pressure to the burning rate of aluminized AP/HTPB propellant and along the way establishing the strand burner facility. The scope included measuring burning rate using the strand burner for five different chamber pressures ranging from 1 atm to 31 atm.

4.2.2 METHODOLOGY

The strand burner in Figure 4.4 is designed for combustion of a propellant strand in continues gas flow up to 31 atm. The body, flange and both end cap are made of low carbon steel. The 23 cm long cylinder has an inner diameter of 10 cm and an outer diameter of 13 cm, offering a wall thickness of 1.5 cm thickness. Each end cap is 1.5 cm thick, making the overall length of the burner 26 cm. Both end caps are square with side length of 21 cm. A 1.2 mm black gasket was inserted between the end caps for a gas tight seal.

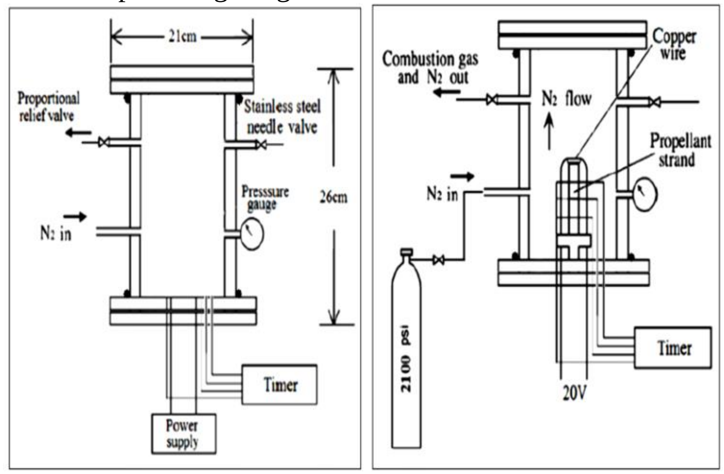

Fig. 4.4 Schematic Diagram of Strand burner

The strand burner was pressurized using nitrogen gas, which is same as the working fluid used by Shigeyuki et al. (S. Hayakawa, 2000). Nitrogen was chosen due to its low cost, availability and low density relative to air. Nitrogen gas was supplied from 22100 psi nitrogen tank at a suitable rate of flow. This will pressurize the burner as well as allowing steady flow of nitrogen at the outlet. Measurement of pressure within the strand burner was made by using a standard bourdon-type pressure gauge. At one of the end cap, there is a mounting stand used to mount the propellant strand. It was made from 5 mm low carbon steel nut as shown in Fig.4.5

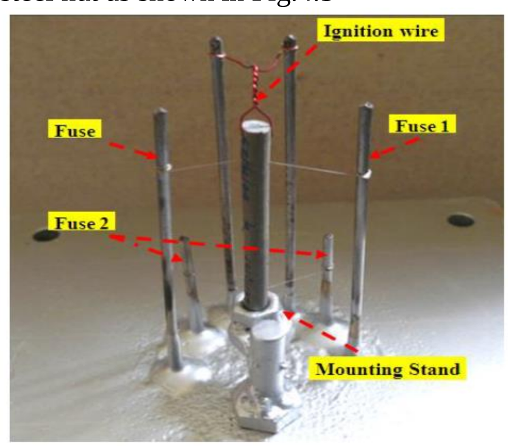

Fig. 4.5 Propellant Strand Moulding

Around the mounting stand, there are six stainless steel rods with a diameter of 2 mm which were used to hold wires/fuses for ignition system and instrumentation timer.

This includes the testing of the burn rate under different temperature, pressure, impurities, and condition. It also requires measurement of physical, chemical, and manufacturing properties, ignitability, aging, sensitivity, to various energy inputs or stimuli, moisture absorption, compatibility with other materials and other characteristics. It is lengthy expensive often hazardous program with many tests, samples, and analyses.

5. COMBUSTION OF SOLID PROPELLANT

5.1 Combustion of Wave Structure

Understanding the decomposition and combustion characteristics of energetic material is crucial before they are employed in actual rocket motors. The combustion characteristics of concern include pressure and temperature sensitivity of the burning rate, propellant surface conditions, and spatial distribution energy release temperature and species concentrations. Combustion of a solid propellant involves an array of intricate physiochemical processes evolving from the various ingredients that consist of the propellant

Most of the individual ingredients in solid propellant formation can burn as mono propellants. It is thus important to study and characterize the burning properties of the specific ingredients that are used in solid propellant. To facilitate the understanding of burning propellants propellant, an example of steady state self-deflagrating mono propellant strand in a stagnant environment is presented. This example is representative of how a homogeneous solid propellant burns with a laminar-premixed flame. The entire combustion wave structure can generally be segmented into three regions

i. Solid phase
ii. Sub surface two-phase or foam layer
iii. Gas phase

5.2 EFFECT OF CATALYST ON PROPELLANT COMBUSTION

The action of catalyst on composite solid propellant and their components is really a vast subjects and numerous paper are available. It is difficult to summarize and present all the work here. However, it is felt that the work having some relevance in explaining the mechanism of the action the catalyst should be presented here before describing the effect of catalyst on the propellant system.

5.3 EFFECT OF CATALYST ON THE BINDER

It is well known that metal salt can act as accelerators for hydrocarbon oxidation and lower the E of hydro peroxide decomposition. Metal catalyst activity during polyolefin auto oxidation has been correlated with the redox potential of the various metal oxides studied. Thus the following reactions have been postulated.

The combustion air flow would be matched to the fuel flow to give each fuel molecule the exact amount of oxygen needed to cause complete combustion. However, in the real world, combustion does not proceed in a perfect manner. Unburned fuel (usually CO and H2) discharged from the system represents a heating value loss (as well as a safety hazard).

Since combustibles are undesirable in the off gas, while the presence of un reacted oxygen there presents minimal safety and environmental

5.4 EFFECT OF CATALYST ON PROPELLANT COMBUSTION

Iron oxide and their components and other transitional metal compounds have long been known to increase the pure potassium nitrate as well as KNO3 based composite propellants.

Various mechanisms have been postulated for catalyst action on the composite and solid propellants. The postulated in a number of ways

1. Through accelerating the gas phase reaction
2. Through exothermic reaction of gasses on the surface of catalyst particles
3. Through promoting heterogeneous reaction
4. Through modifying the pyrolysis mechanism of the solid fuel
5. Through gas phase or heterogeneous reaction promoted by the presence of catalyst particles in crevices at the binder inter face

Pitman observed that coating of the KNO3 particles with effectiveness of the catalyst on the CTPB propellants according to him, the catalyst probably acted in the gas phase to increase the reaction rate of KNO3 and its initial decomposition products.

6. EXPERIMENTAL PROCEDURE

This includes the experimental part that is the process of mixing the chemicals ramming the chemical into the moulds, making propellant strands curing of the propellant, ignition process and precaution to be taken during the ignition of propellant strands. This part of the report gives results of burning rate for various proportions. Several chemicals are used in the process of making propellant strand as studied in previous chapters, the different chemicals that have been used in the experiment are potassium nitrate KNO3, dibutyl phthalate DBP, poly vinyl chloride PVC, aluminium powder, and iron oxide as an oxidizer, plasticizer, binder, fuel respectively. Results are obtained by varying the proportions of oxidizer, fuel, and binder.

The figures below shows the chemicals used in experiment.

Fig. 6.1 CHEMICALS IN BOTTLE

6.1 MIXING PROPORTIONS

The various proportions used for making propellant strands are as follows:

Chemical mixture – 1

TABLE 6.1

DESCRIPTION	COMPOSITION
Potassium nitrate	70
Aluminium powder	8.5
Icing sugar	13
Poly vinyl chloride	7.5
Charcoal	1

Chemical mixture – 2

TABLE 6.2

DESCRIPTION	COMPOSITION
Potassium nitrate	60
Aluminium powder	10
Icing sugar	22.5
Poly vinyl chloride	7.5
Charcoal	0

Chemical mixture – 3

TABLE 6.3

DESCRIPTION	COMPOSITION
Potassium nitrate	65
Aluminium powder	10
Icing sugar	24
Poly vinyl chloride	6.5
Charcoal	0.5

6.2 WEIGHING OF CHEMICALS

Weighing the chemicals in the digital electrical weighing machine which is capable of 100 grams maximum and up to three digits precision after point

Fig.6.2 Digital Weighing Machine

Fig. 6.3 weighing of chemicals in Digital Weighing Machine

6.3 MIXING OF CHEMICALS

Chemical which are already weighed with their respective proportions are mixed in the glass beaker in particular order as taken reference [1].

Sequence of mixing the chemicals in respected proportions

1. Poly vinyl chloride
2. Icing sugar
3. Potassium nitrate
4. Aluminum powder
5. Charcoal

In small portions, ammonium perchlorate is added to initiate the burning of propellant.

- One by one chemical is transferred to the beaker and stirred about 5 – 10 minutes after addition of each chemical for getting the homogeneous composite mixture.

Fig 6.4 Mixing of chemical Composition

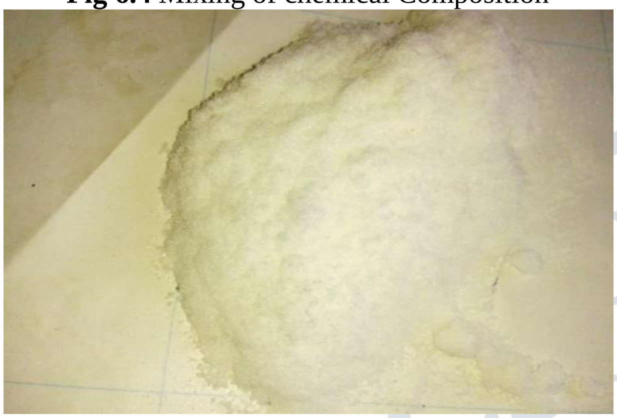

Fig. 6.5 Mixture of PVC, Icing sugar and KNO3

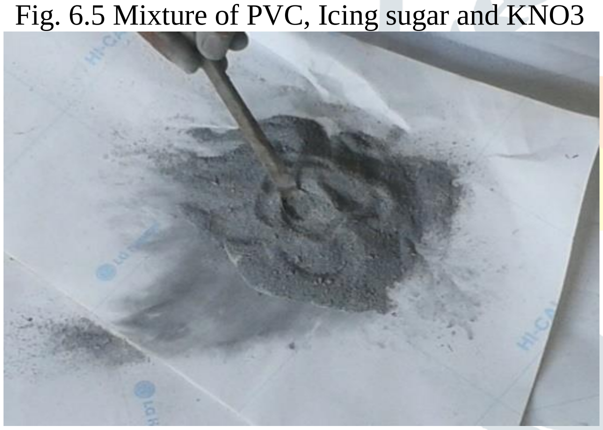

Fig. 6.6 Aluminium powder mixing with KNO3 and Other composition

- Finally all chemicals are mixed in required proportions to form moulds.

Fig.6.6 Mixture of all chemicals without charcoal

6.4 FILLING THE MOULDS WITH CHEMICALS

For preparing the rectangular strands, rectangular mould with uniform square cross section mould are taken by following L/D ratio. Diameter of plastic mould is 15mm and length is 60 mm.

Fig.**6.7** Circular Mould with Plastic

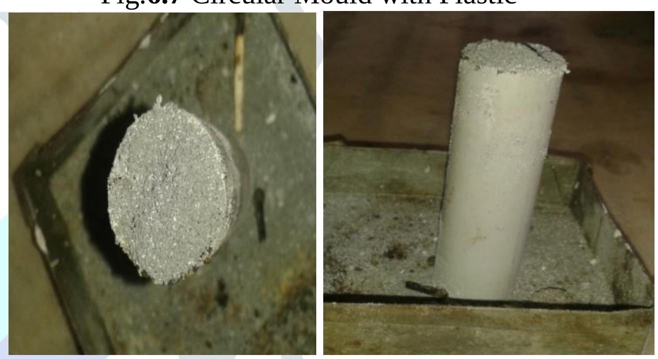

Fig.6.8 Solid cylindrical grain configuration with 60 mm length

Fig. 6.9 Star shape cylindrical grain configuration

6.5 IGITION PROCESS

Solid propellants ignition consist of a series of complex rapid events, which start on receipt of signals and include heat generation, transfer of the heat from the igniter to the motor grain surface, spreading the flame over the entire burning surface area.

Conventionally, the ignition process is divided into three phases for analytical purposes;

Phase1. Ignition time log: the period from the moment the ignite receives a signal until first bit of grain surface burns

Phase2. Flame spreading interval: the time first ignition of the grain surface until the complete burning area ignited.

Phase3. Chamber filling interval: the time for completing the chamber filling process and for reaching equilibrium chamber pressure and flow.

The apparatus ignition set up

The ignition set up is required in order to burn the strands. In present work from 250 volts has been brought down to 12 volt DC supply using a step down transformer. The propellant ignition element use nichrome wire as helical spring. This element is chosen because it resist the voltage about 12 volts and strand heat this ignition set up also consist of a fuming board which lets the gases to flow out into atmosphere.

Fig.6.10 Nichrome wire **and** Electrical Set Up

Solid cylindrical, hollow cylindrical and star shape cylindrical grain configuration strands are placed in the holder. Electrical set up is arranged on to strands and start burning of the strands.

Fig.6.11 Solid cylindrical grain configuration burn with high force

Fig.6.12 star shape cylindrical grain configuration burn with high smoke and force

Fig.6.13 Hollow cylindrical grain configuration burn with high exhaust flames.

6.6 PRECAUTIONS

1. Hand are cover with gloves while chemicals mixing and weighing.
2. Use a mask to avoid poisonous gaseous releasing from burning propellant.
3. Make sure that the step down transformer used to 12 volts.
4. To get homogeneous mixture the mixture should be thoroughly mixed. Such that its decrease density and chemical are should be bonded.
5. Care should be taken while strands are burning time.

7 RESULTS AND DISCUSSIONS

7.1 RESULTS

Ignition of strands are done with the help of nichrome wire and the burn time for each strand complete burning are measure with the help of digital watch and the observations are follows:

Results Obtained from Chemical Mixture -1

Potassium nitrate	60 %
Aluminium powder	10 %
Poly vinyl chloride	7.5 %
Icing sugar	22.5 %
Charcoal	0 %

TABLE 7.1 Calculation of Burn Rate for Chemical Mixture-1

S.NO	TYPE	LENGTH (mm)	BURNING TIME (Sec)	BURN RATE (mm/sec)	Average (mm/sec)
1	SOLID	60	106	0.566	0.577
		60	102	0.5882	
2	HOLLOW	60	92	0.6521	0.629
		60	99	0.606	
3	STAR	60	95	0.6315	0.649
		60	90	0.6666	

- Average burn rate for the above composition is
  1. circular – 0.5771 mm/sec
  2. hollow – 0.62905 mm/sec
  3. star – 0.64905 mm/sec
- Sample variation in the Burn Rate is may be the improper ramming and human errors.

Results Obtained from Chemical Mixture – 2

Potassium nitrate	65 %
Aluminium powder	10 %
Poly vinyl chloride	6.5 %
Icing sugar	24 %
Charcoal	0.5 %

TABLE 7.2 Calculation of Burn Rate for Chemical Mixture-2

S.NO	TYPE	LENGTH (mm)	BURNING TIME (sec)	BURN RATE (mm/s)	AVERAGE (mm/sec)
1	SOLID	60	93	0.645	0.63508
		60	96	0.625	
2	HOLLOW	60	84	0.714	0.7321
		60	80	0.75	
3	STAR	60	78	0.769	0.7742
		60	77	0.779	

- Average Burn Rate for the above composition is
  1. Circular – 0.63508 mm/sec
  2. Hollow – 0.7321 mm/sec
- In the first sample variation in the burn rate is may be the improper ramming and human errors.

Results Obtained from Chemical Mixture – 3

Potassium nitrate	70 %
Aluminium powder	8.5 %
Poly vinyl chloride	7.5 %
Icing sugar	13 %
Charcoal	1 %

TABLE 7.3 Calculation of Burn Rate for chemical Mixture -3

S.NO	TYPE	LENGTH (mm)	BURNING TIME (Sec)	BURN RATE (mm/sec)	Average (mm/sec)
1	SOLID	60	80	0.75	0.7159
		60	88	0.6818	
2	HOLLOW	60	70	0.8571	0.9203
		60	61	0.9836	
3	STAR	60	59	1.0169	0.9923
		60	62	0.9677	

- Average Burn Rate for the above composition is
  1. Circular – 0.7159 mm/sec
  2. Hollow – 0.9203 mm/sec
  3. Star – 0.9923 mm/sec

7.2 PLOTS

Graphical representation of Burn Rate variation with oxidizer weight percentage from the experimental data on ignition:

TABLE 7.4 Graphical representation of oxidizer percentage and burn rate

Oxygen Weight%	Avg. burn rate (Solid Grain)	Avg. burn rate (Hollow Grain)	Avg. burn rate (Star Grain)
60	0.5771	0.62903	0.6490
65	0.63508	0.7321	0.7742
70	0.7159	0.9203	0.9923

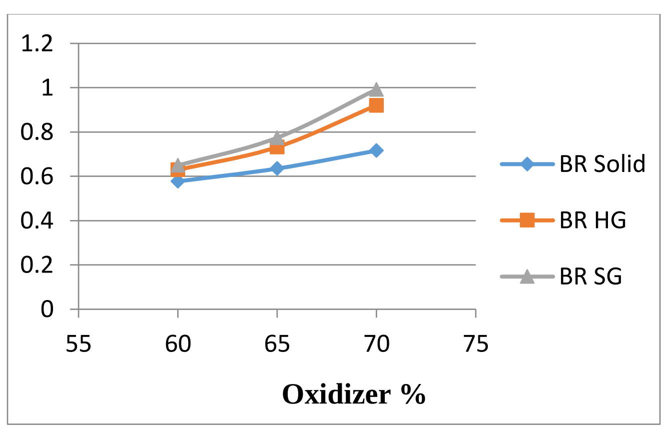

Fig. 7.1 graphical representation of burn rate variation with grain configurations at different weights of oxidizer

➢ Graphical representation of burn rate variation with the burn rate catalyst weight percentage in the chemical composition.

TABLE 7.5 Graphical representation table for catalyst weight percentage and burn rate

S.No	Catalyst Weight %	Burn Rate mm/sec
1	0	0.5771
2	0.5	0.63508
3	1	0.7159

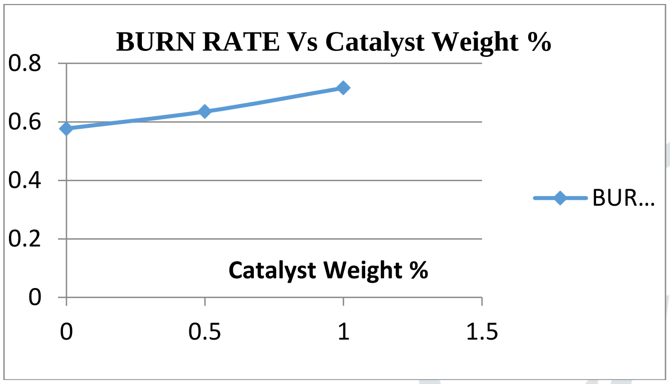

Fig. 7.2 Burn rate variation with catalyst

TABLE 7.6 Graphical representation of burn rate variation with the oxidizer to fuel ratio.

S.No	Oxidizer/Fuel	Burn Rate In Solid
1	6	0.5771
2	6.5	0.63508
3	8.2	0.7159

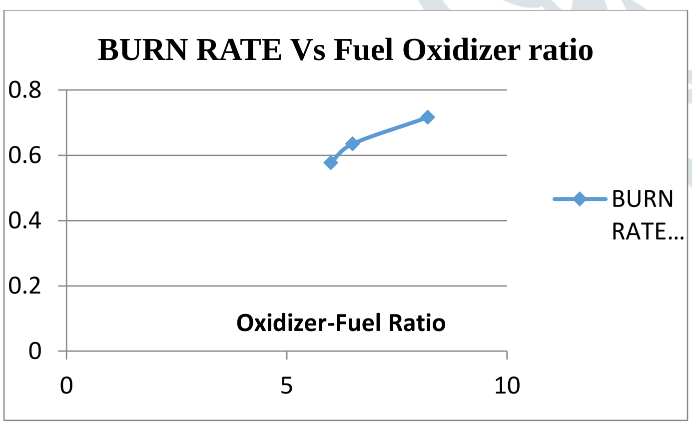

Fig. 7.3 Burn rate variation with oxidizer-fuel ratio.

8. CONCLUSIONS AND FUTURE SCOPE

CONCLUSION

- Burn rate will vary with different grain configurations like solid cylinder, hollow and star grain configurations.
- Burn rate of solid propellant can also be enhances by varying the chemical composition and the burn rate is increased with oxidizer weight percentage up to 70% by weight. This will help to choose require composition for required space missions.
- Burn rate also increases with increase in catalyst addition up to 1% by weight in the chemical composition.
- Oxidizer to fuel ratio also influence the burn rate of solid propellant.

FUTURE SCOPE

- By changing the proportions of chemicals may get more burn rate in solid cylindrical, hollow and star grain configurations of solid propellants

By adding other additives like plasticizers and stabilizers, burn rate of solid propellants increased.

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