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EFFECT OF PROPELLANT FORMULATION ON PROPELLANT PROPERTIES

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ABSTRACT

This paper present the effect of propellant formulations on propellant properties is very crucial to the quality of propellant used in rocket motor. As poor propellant formulation usually leads to unstable combustion and this can lead to a total destruction of the entire structure of the solid rocket motor. For this research work, the centre compositions selected were based on calculation for percentage mass composition from the stoichiometric equation for the combustion process. Hollow bates grains used for the design consist of a mass of propellant of 6 kg, core diameter of 0.050m, throat diameter of 0.036m, grains length of 0.507m, 3 bates and grains diameter of 0.105m. Five samples of different formulations were experimented and as sorbitol increased, propellant properties such as specific impulse, temperature, density and thrust decreased but as potassium nitrate increased these properties increased as well. The increase in propellant properties as potassium nitrate increases indicated the oxidizing properties of potassium nitrate and decrease in propellant properties as sorbitol increases indicated their fuel properties. The specific impulse of 92.68 s and thrust of 1025.27 N of a formulation was the highest of all the propellant formulations considered for the test. This observation revealed that this formulation that produced highest specific impulse and thrust is the best out of all the formulations generated in the design.

Keywords: *Fuel, Oxidizer, Propellant, Potassium nitrate, Temperature, Density, Thrust, Specific impulse*.

I. INRTODUCTION

Propellants are stored matter which when ejected produces a thrust force. Their major applications are in launching projectiles from guns, rockets, and missile systems (Jacqueline, 1998). All propellants are made up of two parts: Oxidizer and Fuel (or reducer). An oxidizer is a component that produces oxygen for reaction with the fuel. Fuel reacts with the oxygen to produces gas for propulsion. The fuel used in space vehicles is very much different from the normal fuel in respect to the following properties, (MFC Propulsion, 2013). Depending on the physical state of fuel and oxidiser, propellants are classified as: Solid propellants, Liquid propellants, Hybrid propellants. (Space Travel Guide, 2014).Different propellants have significant effect on burning rate on various operating conditions as well as formulation (Nnali-Uroh et al, 2016)

In a solid propellant rocket motor, the fuel and oxidizer are stored or placed in the same container. Both are shock sensitive and once fired, there is, in principle, no means of controlling the thrust rate. These problems are overcome using liquid bipropellant motors instead. This requires separate storing for the fuel and oxidizer which results in a complex and more expensive system. The solid rocket motor is the simplest system when compared with other rocket systems (Conny, 2005).In this study, sorbitol based solid propellant is considered, which is a double based solid propellant where fuel and oxidizer are sorbitol and potassium nitrate respectively. Solid propellants are the most commonly used propellant in rocket motors, it is relatively simple to design, highly reliable and easy to manufacture at low cost (Yildirm, 2007).Over the year, there were concerted efforts from different researcher to optimize solid propellant formulation but various combinations of chemical ingredients at different formulations result in diverse physical and chemical properties, as well as combustion characteristics and performance (Yildirim, 2007).

The ballistic parameters considered are temperature, propellant density, specific impulse and thrust.
The design was based on the fact that specific impulse, temperature, density and thrust of the product are functionally related to specific propellant formulation and attempts were made to fit multiple regression equations describing responses to optimal formulation.

This research provides an insight into a way of preventing the negative effect of poor propellant formulation on the propellant properties. It is therefore needed to establish an approach for propellant formulation to maximize propellant performance. Adhering to this proven technique will result in a high quality propellant.

II. METHODOLOGY

The design was based on the fact that specific impulse, temperature, density and thrust of the product are functionally related to specific propellant formulation

Potassium Nitrate is the oxidizer (A) and sorbitol the fuel (B), the chemical equation of the process is:

$$C_6H_{14}O_6 + 3.345KNO_3 \rightarrow 1.870CO_2 + 2.490CO + 4.828H_2O + 2.145H_2$$

$$+1.672N_2 + 1.644K_2CO_3 + 0.057KOH \qquad (1)$$

A centre point was selected with ingredients at levels expected to yield, at least, satisfactory experimental results. With the centre composition selected based on calculation for percentage mass composition from the stoichiometric equation for combustion process, the normal x_i ratios were calculated by using the normal weight composition of the formulation given in Table 1.

Table 1.Propellant Formulation at the Design Centre Point

Ingredients	**Centre Point (%) mass**
A. Potassium Nitrate as oxidizer	65
B. Sorbitol as fuel	35
Total	**100**

The design depended upon the symmetrical selection of variation increments about the centre composition. These levels of variation were chosen to be within the range of formulation, and the increments were carefully selected, as interpretation of the result was valid only within the experimental limits.
The increment was chosen as: $\pm 20\% = \pm 0.2$

From this equation, the centre point design is chosen as: $x_1 = \frac{A}{B} = \frac{65}{35} = 1.86$

Table 2.Experimental Increments and Values of Coded levels

		X_i coded levels		
Ingredients (x_i)	**±Increment**	**-1**	**0**	**1**
x_1	±0.2	1.49	1.86	2.23

Equation relating Actual x_i and Coded X_i Ratios

$$X_1 = \frac{(x_1 - 1.86)}{0.2} \qquad (2)$$

The composition of propellant has the form, A (Potassium Nitrate) + B (Sorbitol) = 100%.
So, A+B=1

$$x_1 = \frac{A}{B}$$

$$x_1 = \frac{0.65}{0.35} = 1.86, \therefore x_1 = 1.86$$

$A = \frac{x_1}{1+x_1}$ $B = \frac{1}{1+x_1}$ For values of $-1 \leq X_1 \leq 1$;

Table 3. Central Composite Design Arrangement for Propellant Formulations

Sample	**Coded level** **X₁**	**(Actual** **(A)**	**Composition)** **(B)**
Sample 1	-1	0.624	0.376
Sample 2	0	0.650	0.350
Sample 3	1	0.673	0.327
Sample 4	0.5	0.662	0.338
Sample 5	-0.5	0.638	0.362

A central composite rotatable design was adopted for generating the resulting weights for each ingredient in different propellant formulation (Cocharan and Cox, 1957).

The prepared propellant was inserted into the combustion chamber of the De Laval nozzle solid rocket motor where it was ignited. The specific impulse, temperature, density and thrust were measured using data acquisition system connected with rocket motor chamber. This measuring instrument is very efficient and reliable. It cannot be distorted or damaged as a result of high pressure or temperature to be generated by the firing test (Mungas*et al.*, 2003).

III. RESULTS AND DISCUSSION

The hollow bates grains used for the design consist of: mass of propellant (m_p) = 6 kg, core diameter (d_o) = 0.050m, throat diameter (d_t) = 0.036m, grains length (L_{grain}) = 0.507m, bates number (N) = 3 and grains diameter (d_m) = 0.105m.

Table 4.Effects of Propellant Formulation on Propellant Properties

Expt. Run	**Composition** **A (kg)**	**(mass)** **B (kg)**	***I*sp (s)**	**Responses** **Tc (K)**	ρ (Kg/m³)	**F (N**
1	3.744	2.256	77.8481	1465	1819.1	578.018
2	3.900	2.100	87.7362	1603	1837.3	876.189
3	4.038	1.962	92.6800	1716	1853.7	1025.270
4	3.972	2.028	91.7800	1663	1845.8	998.170
5	3.828	2.172	83.6910	1540	1828.8	754.210

As shown in Table 4, for the firing test of the considered formulations, as sorbitol (B) increased, propellant properties (specific impulse, temperature, density and thrust) decreased but as potassium nitrate increased these properties increased as well. The increase in propellant properties as potassium nitrate increases indicated the oxidizing properties of potassium nitrate and decrease in propellant properties as sorbitol increases indicated their fuel properties.

This is because as oxidizing value of materials for a propellant increased, there is corresponding increase in propellant properties. This was possible owning to the oxidizer, potassium nitrate that boosts the heat of combustion and combustion temperature which aids the chemical energy generation being transformed to thrust by nozzle. It is observed that the specific impulse, 92.68 s and thrust, 1025.27 N of formulation for sample 3 was the highest of all the propellant formulations considered for the test. This observation revealed that formulation for sample 3 that produced highest specific impulse and thrust is the best out of all the formulations generated in the design.

In general, the propellant formulation for sample 3 that yielded maximum specific impulse and thrust is the best out of all the formulations verified with the static test for double based propellant of sorbitol and Potassium nitrate composition. Therefore, potassium nitrate enhanced the heat of combustion, combustion temperature and hence the specific impulse which is the measure of propellant performance. This observation is corroborated by the Richard Nakka's(2013) study on solid rocket propellant design. The scientist worked on sorbitol and potassium nitrate and observed that as sorbitol increases, specific impulse decreases while as potassium nitrate increases, specific impulse increases also (Nakka, 2013).

Some selected surfaces are presented in Figures 1 to 4. The relationship of specific Impulse with solid propellant formulation is shown in Figure 1. As the potassium nitrate ratio increases so also there is an increase in specific impulse, whereas, when moving in the direction of sorbitol ratio, an increase in the ratio brings a decrease in specific impulse until an optimum specific impulse is achieved.

Similarly, the relationship of temperature with propellant formulation is shown in Figure 2. The unit positive change in potassium nitrate ratio gives an increase in temperature, but a positive change in sorbitol ratio brings a decrease in temperature until an optimum temperature is achieved. The behaviour of specific impulse and thrust with the propellant formulation are very similar which implies that the two responses could be related.

Also, the relationship of density with propellant formulation is shown on Figure 3. The increase in sorbitol ratio yields a decrease in density whereas an increase in potassium nitrate ratio resulted into an increase in density until an optimum density is achieved. The relationship of thrust with propellant formulation is shown on Figure 4. The increase in sorbitol ratio yields a decrease in thrust whereas an increase in potassium nitrate ratio resulted into an increase in thrust. The behaviour of density and temperature with the propellant formulation are very similar. This suggested that the two responses are much related.

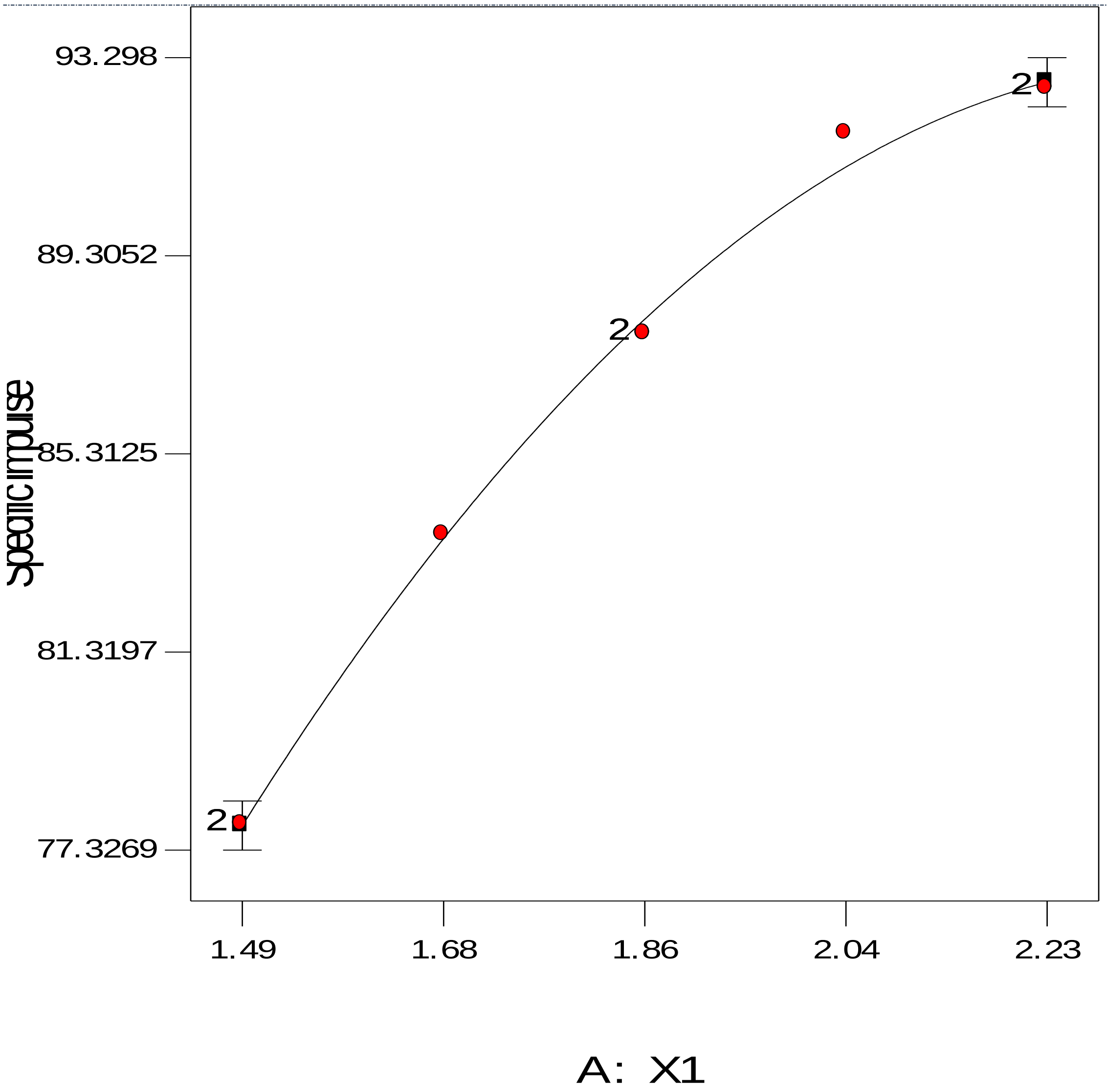

Figure 1.Effect of Propellant formulation on Specific Impulse

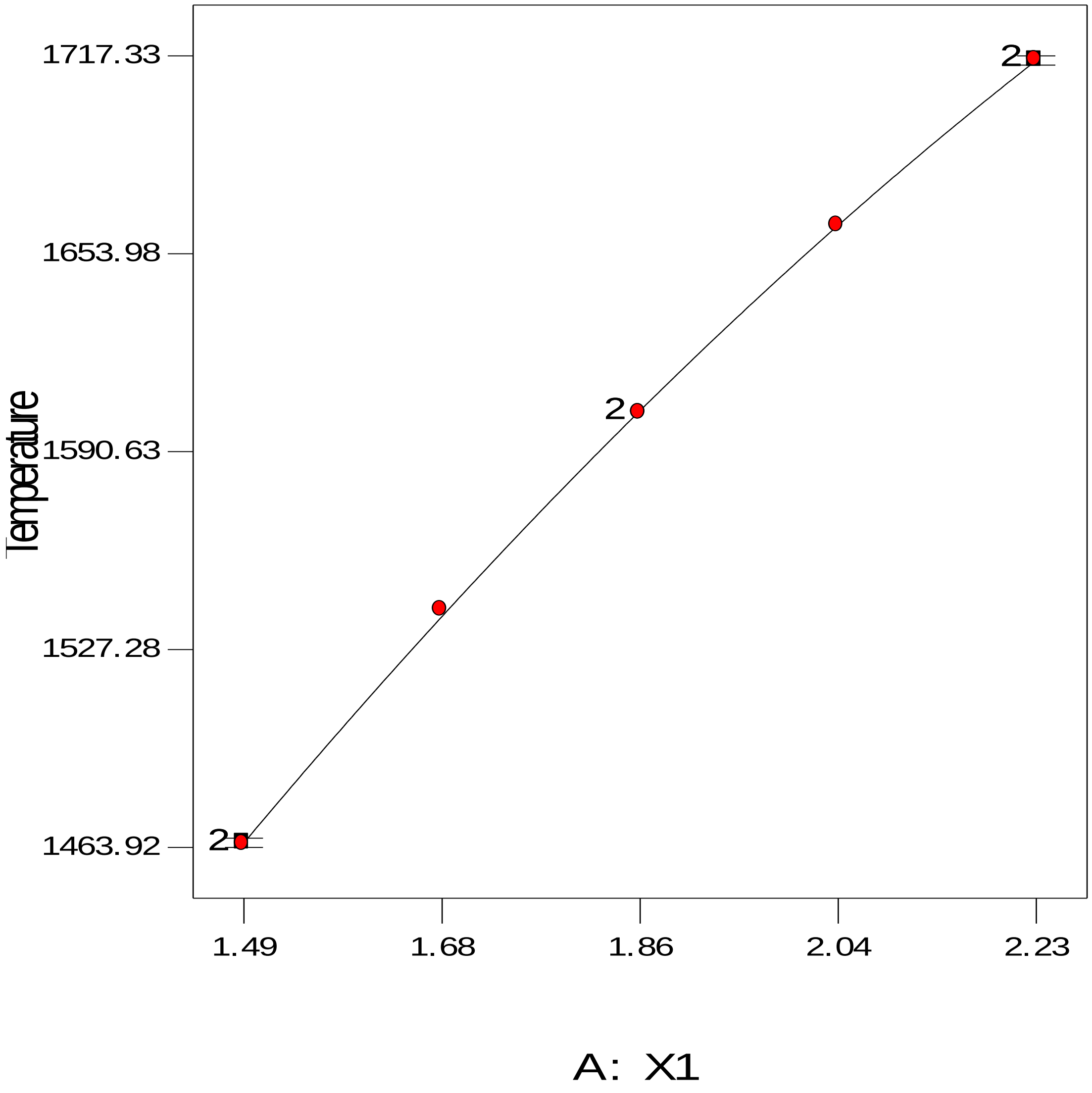

Figure 2.Effect of Propellant formulation on Temperature

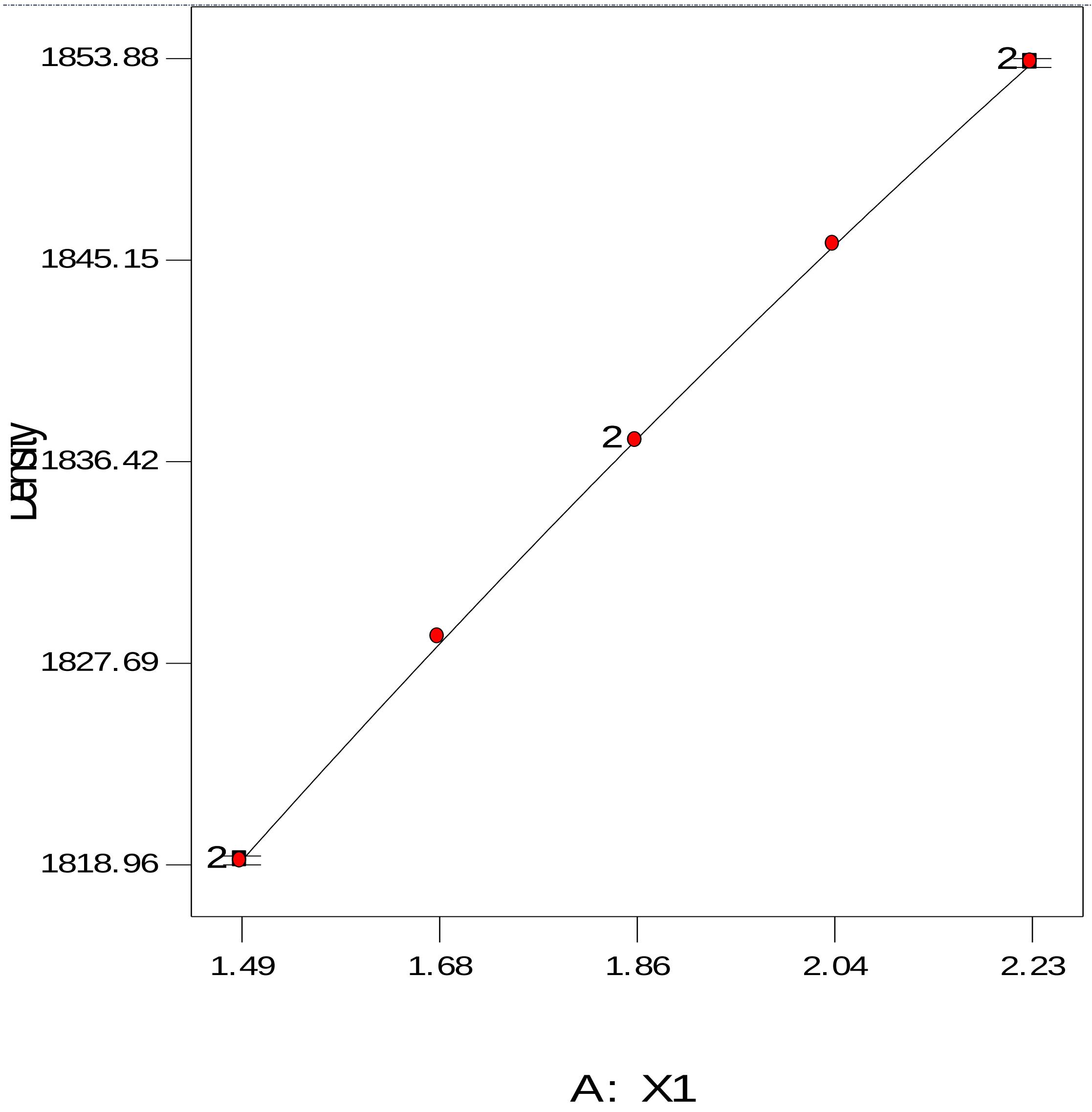

Figure 3.Effect of Propellant formulation on Density

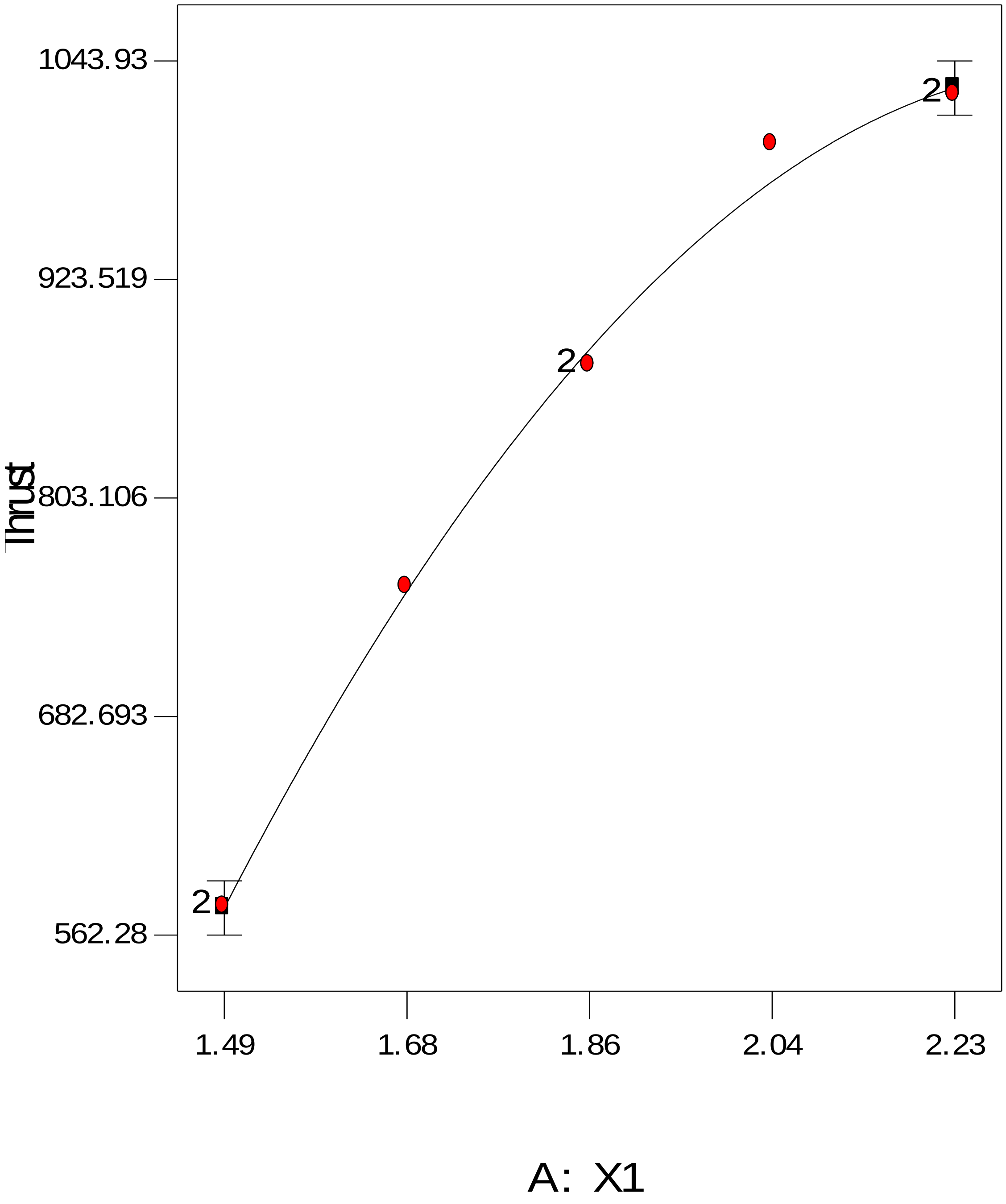

Figure 4.Effect of Propellant formulation on Thrust

IV. CONCLUSIONS

The effect of propellant formulations on specific impulse, temperature, density and thrust of Potassium Nitrate Sorbitol propellant was studied. In all samples, the specific impulse and thrust increased with increase in potassium nitrate which is the oxidizer and decreased with increase in sorbitol. This indicated that as oxidizing value of materials increased, there is a corresponding increase in propellant properties. Therefore, potassium nitrate enhanced better propellant performance. Hence, the propellant ingredients and their proportions determine the solid propellant performance.

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