Preparation of KNSB Composite Sugar Propellant: An Investigation and Commentary

on

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1 Introduction

This report aims at investigating and commenting on an optimal procedure for lab-scale production of Potassium Nitrate-Sorbitol Composite Sugar Propellant (KNSB). This investigation is essential as it will form a basis for future synthesis and will mitigate potential failures during testing of the Solid Rocket Motor (SRM).

The KNSB produced through this procedure will be sufficient for two to four grains, depending on the target size of grain and class of SRM of the enthusiast.

2 Method

2.1 Apparatus and Reagents

Reagents

- Fine Potassium Nitrate ($KNO_{3(s)}$)
- Liquid Sorbitol ($C_6H_{14}O_{6(l)}$)

Apparatus

- Casting mold
- Casting foil

- Core rods
- Stopwatch
- Skillet
- Induction Oven
- Electronic Balance
- Silicon Spatula
- Gloves
- Face Mask
- Goggles
- Pestle & Mortar
- Grease
- Zip-lock bags Silica Gel beads

2.2 Procedure

1453.60 g of $C_6H_{14}O_{6(l)}$ were weighed and added into the skillet, before being transferred onto the induction oven that was set at 240°C. As the $C_6H_{14}O_{6(l)}$ was boiled, 1889.68 g of $KNO_{3(s)}$ were weighed and set aside, as the casting molds were being assembled and lined with casting foil. After 30 minutes had elapsed on the stopwatch, the temperature was reduced to 180°C and the stirring of the $C_6H_{14}O_{6(l)}$ began, while checking its color. After 5 minutes, the temperature was further reduced to 90°C after a color change from colorless to light caramel was noticed. Small amounts of $KNO_{3(s)}$ were added while stirring the contents in the skillet and the temperature was increased to 120°C. After 20 minutes, after the $KNO_{3(s)}$ was added, temperature was reduced to 60°C while stirring. After 10 minutes, the mixture turned white in color and the temperature was raised to 90°C in preparation for casting. The prepared KNSB was then transferred to two casting molds and two greased core rods were inserted in the middle of the cast. After 3 hours had elapsed, the core rods were removed from the casting molds. The casting molds, still with the KNSB, was transferred in to two zip-lock bags, quarter-filled with silica beads. After 2 days, the KNSB grain was de-molded and then sealed in the beaded zip-lock bag.[1]

3 Calculation

3.1 Determining the Optimal KNSB Ratio

The steps below outline how we came up with the weights of reagents used in the preparation of KNSB. This is for two Grains. Further optimization of these calculations is encouraged. [2]

<u>*Soln:*</u> Total Propellant mass is $6,320.00\,g$ for a 5 grain, Class M motor. The mass of a single grain with core diameter of $32.50\,mm$ will be:

$$\left(\frac{6,320.00}{5}\right)\,g = 1,264.00g$$

Accounting 15% for wastage, the expected mass of Grain will be:

$$M_{KNSB}:\ 1.15 \times 1,264.00 = 1,453.60\,g$$

Taking optimum $\mathrm{KNO_{3(s)}}$ to $\mathrm{C_6H_{14}O_{6(l)}}$ ratio to be 65 : 35, the mass of $\mathrm{KNO_{3(s)}}$ to be weighed will be:

$$M_{\mathrm{KNO_{3(s)}}}:\ 0.65 \times 1,453.60 = 944.84\,g$$

Expected mass of $\mathrm{C_6H_{14}O_{6(l)}}$ to be weighed will be:

$$M_{\mathrm{C_6H_{14}O_{6(l)}}}:\ 0.35 \times 1,453.60 = 508.76\,g$$

Since there is 70% of $\mathrm{C_6H_{14}O_{6(l)}}$ in solution, the adjusted mass of $\mathrm{C_6H_{14}O_{6(l)}}$ will be:

$$\left(\frac{100 \times 508.76}{70}\right)g = 726.80g$$

Adjusting for 2 grains:

$$M_{\mathrm{KNO_{3(s)}}} = 2 \times 944.84 = 1,889.68\,g$$

$$M_{\mathrm{C_6H_{14}O_{6(l)}}} = 2 \times 726.80 = 1,453.60\,g$$

3.2 Comment on the % H_2O in Sorbitol

We carried out an investigation on the moisture content of Sorbitol and we found some interesting results. This leads to the modification of the calculation of the optimal KNSB ratio (*See* **??**).

W_1	W_2	$\%H_2O_{experimental}$	$\%H_2O_{theoretical}$	Elapsed Time
18.99 g	14.00 g	26.30	26.28	67 min 12 s
19.01 g	13.90 g	26.85	26.88	56 min 34 s
18.98 g	14.07 g	25.90	25.87	69 min 04 s

Table 1: *Testing H_2O of Sorbitol using KERB DAB Moisture Analyzer*

In Table 1 above:

- W_1 refers to the initial mass of the sorbitol and the lid
- W_2 refers to the final mass of the sorbitol and the lid

1 1

These are results from heating the 70% solution at 105°C, with the respective elapsed times provided.

The theoretical value for the $\%H_2O$ calculation was obtained using the formula [3]:

$$\%H_2O_{theoretical} = \frac{W_1 - W_2}{W_1} \times 100$$

We found that using the mean $\%H_2O_{experimental}$ to be favorable in the synthesis. $\therefore$ Adjusting the KNSB ratio calculations, the mean $\%H_2O$ found to be:

$$\left(\frac{26.30 + 26.85 + 25.90}{3}\right)\% = 26.35\%$$

Corrected mass of $C_6H_{14}O_{6(l)}$ to be weighed will be:

$$\left(\frac{100 \times 508.76}{73.65}\right)\ g = 690.78\ g$$

...and for 2 grains:

$$M_{C_6H_{14}O_{6(l)}} = 2 \times 690.78 = 1,381.56\ g$$

[1] You'll notice that W_0 isn't considered in this experiment. This is because the KERB DAB uses **thermogravimetric analysis** that factors out the weight of the measuring lid. You'll notice that the theoretical and experimental percentages aren't that far apart.

3.3 Error Analysis

The basis of the error in masses of the reagents will be mostly due to the accuracy and precision of the electronic balance and therefore systematic in nature. Also, experienced in the mass of $C_6H_{14}O_{6(l)}$ weighed. We'll now provide the absolute and relative error encountered in this experiment.
<u>*Soln:*</u> The absolute error is given by:

$$\Delta x = |x_0 - x|$$

...where x_0 is the **measured value** and x is the **actual or ideal value**

$$\Delta\, x_{C_6H_{14}O_6} = |(1453.60 - 1381.56)|\, g = 72.03\, g$$

The relative error is given by:

$$\begin{aligned}\delta x_{C_6H_{14}O_{6(l)}} &= \frac{\Delta x_{C_6H_{14}O_{6(l)}}}{x} \\ &= \frac{72.03}{1381.56} \\ &= 0.05213671501 \\ &= 5.21 \times 10^{-2}\end{aligned}$$

...and the percentage error will be:

$$\begin{aligned}\%\, \delta x_{C_6H_{14}O_{6(l)}} &= \delta x \times 100\% \\ &= 5.21 \times 10^{-2} \times 100\% \\ &= 5.21\%\end{aligned}$$

4 Discussion

The principal reagents serve as the oxidizer and fuel for the propellant. A stoichiometric balance of 65 : 35 was deemed optimal as it provides for efficient combustion of the KNSB grain. Particle size of the oxidizer should also be considered as the finer the particle of the nitrate, the better erosive burning and incomplete combustion of the grain shall be mitigated.

4.1 Precautions and Best Practices

- Care should be taken while adjusting the governing parameters i.e. Temperature and time so as to avoid the splitting of the nitrate and fuel in the grain obtained.
- Try to avoid an open element hot plate or an open flame when preparing the grain to avoid potential accidents to yourself and the environment

- Avoid overheating the grain slurry before casting is done. This is to ensure that the plastic molds are preserved during casting.
- Wear Personal Protective Equipment(PPE) i.e. Overalls, safety boots, gloves e.t.c during grain preparation.

5 Conclusion

- The KNSB Composite Sugar Propellant was successfully prepared using the dry melt method.

References

[1] R. Nakka, *Knsb propellant*, Jul. 2023. [Online]. Available: `https://www.nakka-rocketry.net/sorb.html`.

[2] J. Kimanthi Kioko, M. Kinyua, N. Ndung'u, *et al.*, *N-3.5 rocket launch (2024): Solid propulsion: Technical report.* 2024. [Online]. Available: `https://nakujaproject.com/resource/N3.5_Solid_Propulsion_Technical_Report.pdf`.

[3] A. I. Vogel, *Vogels Textbook Of Quantitative Chemical Analysis.* Pearson Education, 2006, ISBN: 9788177581805. [Online]. Available: `https://books.google.co.ke/books?id=b5WbqDuL0foC`.

Appendices

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