Experiments with Modified KNSB Formulations to Achieve Slurry Viscosity Reduction

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Objective

The purpose of this experiment is to investigate minor alterations to the KNSB propellant formulation to attempt to achieve a reduction in slurry viscosity. In particular, it has been determined that propellant prepared by the "vacuum-evaporation" method is fairly viscous, and handling of such propellant could be facilitated if a means could be found to reduce the slurry viscosity. Since cure time and burn rate could be affected by such alterations, these properties are likewise investigated. All three propellant properties are of particular importance to the *Sugar Shot to Space* project.

Apparatus and materials

Sorbitol powder: 329.1 grams, "as obtained" from PVCONLY.COM
KNO3 granules : 178.5.1 grams, *K-Power* fertilizer
The KNO3 was dried in an oven at 160°C. for 2 hours, then ground to a very fine powder using a *Braun* electric coffee grinder, 45 seconds per 2 tablespoon batches.

Additives:

1) Red iron oxide (Fe2O3), concrete pigment
2) Carbon, activated "*Fluval*" aquarium grade, balled milled to "air-float" fineness.
3) Castor oil, "*Xenex*" USP grade
4) Heavy duty liquid laundry detergent, generic brand

A cast aluminum deep fryer with thermostatic control was used for melting the propellant. The thermostat was set at 140°C (285° F)

Slurry temperature measurements were made with a K-type thermocouple probe connected to a DVM with temperature measurement display capability.

Digital scale used for mass measurement: 200 gram capacity with 0.01 gram resolution;

Procedure

Six batches of modified-formulation propellant were prepared. Sample #1 was standard KNSB (65/35 O/F ratio). Samples #2 - #5 were each basic KNSB doped with 0.5% additive. The sample #6 had a modified O/F ratio of 64/36. Details of the formulations are presented in Table 1.

	Sample #1	Sample #2	Sample #3	Sample #4	Sample #5	Sample #6
	grams					
KNO3	55.0	55.0	55.0	55.0	55.0	54.1
Sorbitol	29.6	29.6	29.6	29.6	29.6	30.5
Additive		0.42 RIO	0.42 Carbon	0.42 Castor oil	0.42 Detergent	

Table 1 – Details of sample formulations

For samples #1 - #3, and #6, the dry ingredients were weighed out then combined into a plastic *Tupperware* container, together with a few glass pebbles to aid mixing and to break up any clumps. The mixtures were then blended using a rotating mixer (turning at 30 RPM) for 2 hours each.

For samples #4 - #6, only the dry ingredients were similarly blended. The liquid additives were introduced during the melting process and blended into the slurry by stirring.

Each of the samples was individually melted in the deep fryer, qualitatively noting the viscosity of each at the target temperature of 135-140° C. (275-284° F). Viscosity was estimated and ranked by the scale shown below, originally used by Dustin Brown for a similar study of KNSB "alloy" compositions (ref. http://www.integrity.com/homes/brodwcjj/PDT-5a.html)
1+ = scoopable
2+ = very scoopable
3+ = pourable
4+ = very pourable
To elaborate, for this experiment pourable infers that a tablespoon of slurry, held vertical, would at least partly drain off the spoon. Scoopable infers that no draining of slurry would occur unless encouraged using a second utensil
.
Several strands for burn rate measurements were made from each batch. Additionally, a tablespoon of slurry of each sample was deposited onto a sheet of paper in an attempt to judge viscosity by the degree of "slump". These slugs were also used to estimate the degree of flexibility of the sample over the course of 3 days. A photo of the slugs is provided in Figure 2.

Burn rate measurements were made a minimum of 48 hours after casting. All strands were painted with high-heat aluminum paint. Three gauge marks were drawn on each strand and the distance between the first and second mark (L1) and the first and third mark (L2) were measured and recorded. The strands were mounted vertically and ignited with a red hot strip of flat steel at the top end.

The strands were also used to estimate the "cure time" of the propellant. This involved gently trying to bend a strand of each formulation, and rating the degree of flexibility. Cured propellant would not tend to deform and would therefore be considered to be rigid.

Results & Discussion

The potassium nitrate for this experiment had been ground up particularly fine in order to obtain a slurry of a more viscous nature. The intent was to more closely represent the viscosity of propellant prepared by the "vacuum-evaporation" method, which tends to be more viscous than that prepared by the conventional "melt & cast" method.

Doping was limited to 0.5% for two reasons. One, to minimize any effect on propellant performance, and secondly, it was felt that any viscosity change resulting from the addition of the doping agent would be more noticeable if kept to a small amount.

Based on my own prior experience, and that of others, red iron oxide has been known to reduce slurry viscosity. Limited experience had indicated that carbon powder likewise lowers viscosity. Carbon has the positive trait that it is a fuel. Castor oil was chosen based on reports on the *SugPro* discussion forum that oil is effective in reducing slurry viscosity. Castor oil was specifically chosen over other types of oil (e.g. vegetable oil) for this experiment owing to its excellent lubricating properties (castor oil in used as a lubricant in model airplane fuel), which was felt might translate into a less viscous slurry. Liquid laundry detergent was chosen based on a report that it is an effective viscosity reducing agent and one that apparently has negligible effect on burn rate. Finally, as an alternative to doping, viscosity reduction can be achieved by making the propellant more fuel-rich. As such, a slightly modified formulation with an O/F ratio of 64/36 was chosen for this experiment.

Table 2 shows the results of the slurry viscosity rating part of this experiment.

	Sample #1	Sample #2	Sample #3	Sample #4	Sample #5	Sample #6
	Basic	RIO	Carbon	Castor oil	Detergent	64/36
Viscosity rating	1++	2++	2++	1+	2+	2+

Table 2 – Results of viscosity assessment.

It is interesting to note that none of the formulations were pourable (3+ rating). This was not too surprising, due to the very fine particle size of the potassium nitrate. The sample with the castor oil seemed to experience a slight increase in viscosity over basic KNSB. The least viscous samples were the ones doped with iron oxide and carbon powder. The overall range from the most viscous sample to the least viscous was not dramatic.

The attempt at judging viscosity by the slumping of a spoonful of slurry deposited on a sheet of paper was not particularly successful, perhaps due to the onset of cooling. All samples behaved in a seemingly similar manner, with no significant slumping occurring unless the table on which the sample was placed was lightly tapped.

Immediately after cooling, all samples were found to be fully flexible. The degree of flexibility was checked after 48 and after 72 hours. The results of this assessment are provided in Table 3.

Time duration since casting (hrs)	Sample #1 Basic	Sample #2 RIO	Sample #3 Carbon	Sample #4 Castor oil	Sample #5 Detergent	Sample #6 64/36
10	Fully flexible	Fairly rigid	Fairly rigid	Fully flexible	Fully flexible	Fully flexible
48	Fairly flexible	Rigid	Rigid	Flexible	Fairly flexible	Fairly flexible
72	Fairly rigid	Rigid	Rigid	Fairly flexible	Fairly rigid	Fairly rigid

Table 3 – Results of degree-of-curing assessment.

All strands were found to burn in a very stable manner except sample #4, with the castor oil additive. These particular strands burned slowly (at half the rate of basic propellant) and tended to feature an uneven burning surface. The flame appeared to be cooler than usual; however, this may simply have been a consequence of the slow burn rate. The burn rate of the other strands was very similar, with the exception of the iron oxide doped sample, which had a greatly increased burn rate (nearly 50% greater). The results of burn rate measurements are presented in Tables 4 to 9. A graphical summary of the results is presented in Figure 1.

Sample 1						
	L1	L2	time 1	time 2	rate 1	rate 2
Strand	(mm)	(mm)	(sec.)	(sec.)	mm/sec	mm/sec
1	13.8		5.40		2.56	
2	20.3	41.0	7.99	16.50	2.54	2.48
3	15.5		6.15		2.52	
4	15.0	25.0	6.11	9.87	2.45	2.53
5	12.0	22.5	4.55	8.85	2.64	2.54
				average	2.5	**2.5**

Table 4 – Results of burn rate measurements, basic KNSB.

Sample 2						
	L1	L2	time 1	time 2	rate 1	rate 2
Strand	(mm)	(mm)	(sec.)	(sec.)	mm/sec	mm/sec
1	18.0	33.5	5.21	9.47	3.45	3.54
2	19.1	41.4	5.24	11.32	3.65	3.66
3	25.6	57.1	7.05	15.75	3.63	3.63
				average	3.6	**3.6**

Table 5 – Results of burn rate measurements, KNSB doped with red iron oxide.

Sample 3						
	L1	L2	time 1	time 2	rate 1	rate 2
Strand	(mm)	(mm)	(sec.)	(sec.)	mm/sec	mm/sec
1	16.0	27.6	5.99	10.56	2.67	2.61
2	19.9	35.4	7.90	13.72	2.52	2.58
3	21.0	42.3	7.84	16.22	2.68	2.61
4	18.1	36.0	6.65	13.78	2.72	2.61
5	13.5		4.97		2.72	
				average	2.7	**2.6**

Table 6 – Results of burn rate measurements, doped with carbon.

Sample 4						
	L1	L2	time 1	time 2	rate 1	rate 2
Strand	(mm)	(mm)	(sec.)	(sec.)	mm/sec	mm/sec
1	14.2	26.9	11.27	20.07	1.26	1.34
2	20.5	44.0	16.80	35.85	1.22	1.23
3	13.1		10.11		1.30	
4	18.5		15.03	35.85	1.23	
				average	1.3	**1.3**

Table 7 – Results of burn rate measurements, doped with castor oil.

Sample 5						
	L1	L2	time 1	time 2	rate 1	rate 2
Strand	(mm)	(mm)	(sec.)	(sec.)	mm/sec	mm/sec
1	14.5		6.06		2.39	
2	20.0	33.3	7.33	12.50	2.73	2.66
3	17.9		6.66		2.69	
4	14.1	25.5	5.35	9.72	2.64	2.62
5	19.3		7.24		2.67	
				average	2.6	**2.6**

Table 8 – Results of burn rate measurements, doped with liquid detergent.

Sample 6						
	L1	L2	time 1	time 2	rate 1	rate 2
Strand	(mm)	(mm)	(sec.)	(sec.)	mm/sec	mm/sec
1	14.0	25.0	5.61	10.28	2.50	2.43
2	17.6	31.0	6.87	12.47	2.56	2.49
3	12.2	22.5	5.05	9.18	2.42	2.45
				average	2.5	**2.5**

Table 9 – Results of burn rate measurements, 64/36 O/F KNSB.

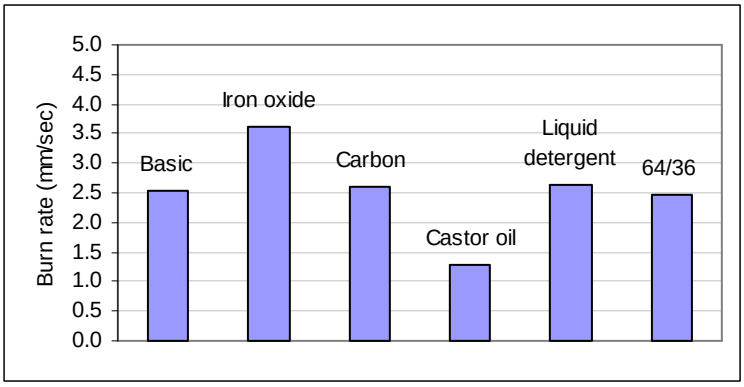

Figure 1 –Summary of ambient burn rate measurements of the six samples.

Figure 2 –Photo of propellant slugs.

Conclusions

This experiment demonstrated that slurry viscosity can be achieved with the addition of certain additives, even in tiny amounts (0.5%). A minor reduction could also be achieved by making the formulation slightly more fuel rich. The most effective additives were red iron oxide and carbon, with liquid laundry detergent being slightly less effective. Red iron oxide had the disadvantage of greatly increasing the burn rate. The burn rate for the other two additives was essentially unchanged from basic KNSB. Carbon would likely be the best choice since it is a fuel and additionally acts as an effective opacifier. Another plus feature of carbon is the reduction in propellant curing time over basic KNSB.