*Eutectic Sugar Propellant Research, Part IV*

Rev. 2011/09/26

**Ignition of liquid $KNO_3$-$NaNO_3$-Mannitol propellant**

Experiment setup:

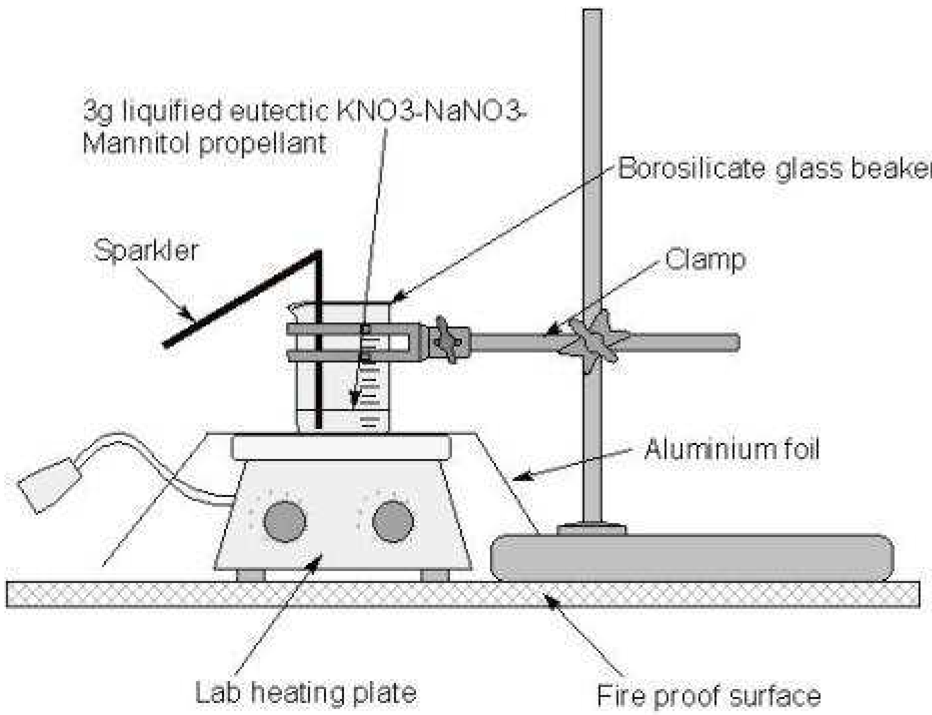


*Fig. 1Experiment setup ignition test liquid eutectic $KNO_3$-$NaNO_3$-Mannitol propellant*

The propellant was heated up to 170°C till it was completely liquefied, then ignited with a sparkler. It showed that one spark was enough to ignite the propellant. The propellant deflagrated in a split of a second.

Ignition test video: http://www.youtube.com/watch?v=pcFp9dcoEL8

The high burn rate of the liquid propellant and the low viscosity makes a liquid eutectic oxidizer/sugar alcohol based rocket engine feasible. In its simplest form the rocket engine could look like following sketch:

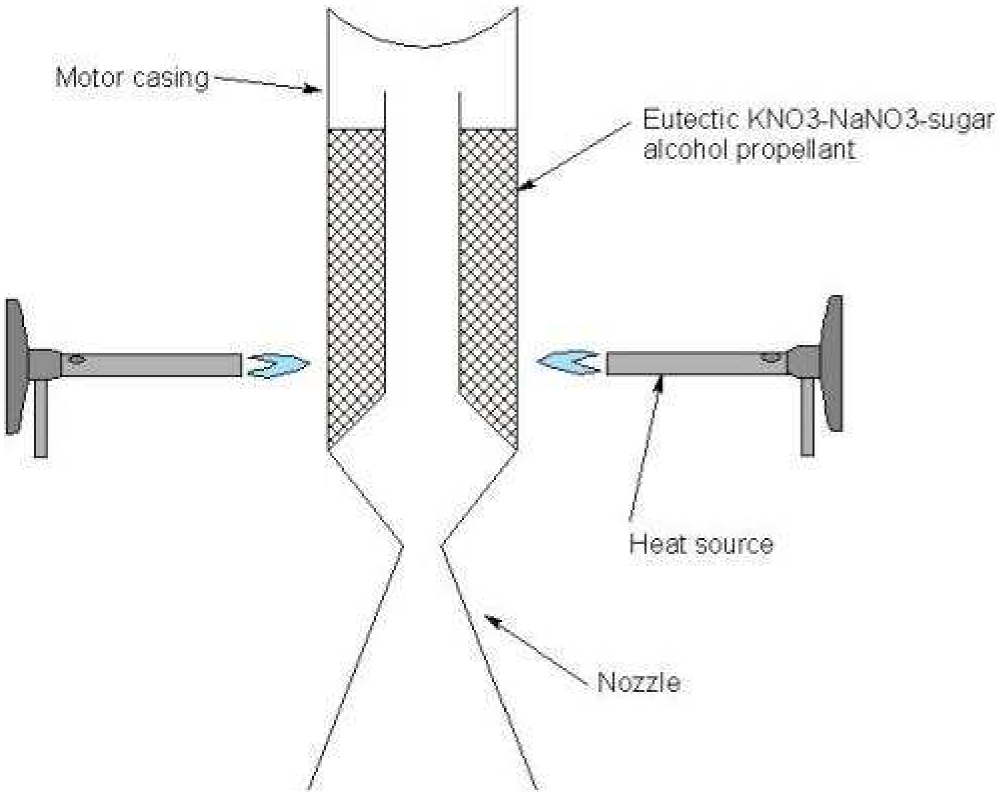


*Fig. 2 Sketch of a liquid $KNO_3$-$NaNO_3$-Mannitol propellant rocket engine*

**Strand burn test**

A strand burning test was conducted using eutectic $KNO_3$-$NaNO_3$-Mannitol propellant. The mold was made from aluminum foil, wrapped around a pencil. The liquid propellant was then poured into the mold.
It was not possible to complete the strand burning test. The strand went out several times. It was even not possible to ignite the strand with a butane torch in a proper manner. The strand ablated to a small pool till ignition occurred. The deflagration was quite violently then (see fig. 5-7).
It was observed that the propellant is the easier to ignite the larger the surface and mass of the propellant is --- less ablating due to the greater dissipation of heat.
Another strand was made adding 5% red iron oxide ($Fe_2O_3$). This strand burned down without any problems. The measured burn rate was approx 1.77 mm/s (see fig. 8-9) at 23°C and 1046 hPa.

Video of the strand burn rate test, using red iron oxide:
http://www.youtube.com/watch?v=zVM6To1dy1s

*Fig. 3 Cast $KNO_3$-$NaNO_3$-Mannitol propellant strand*

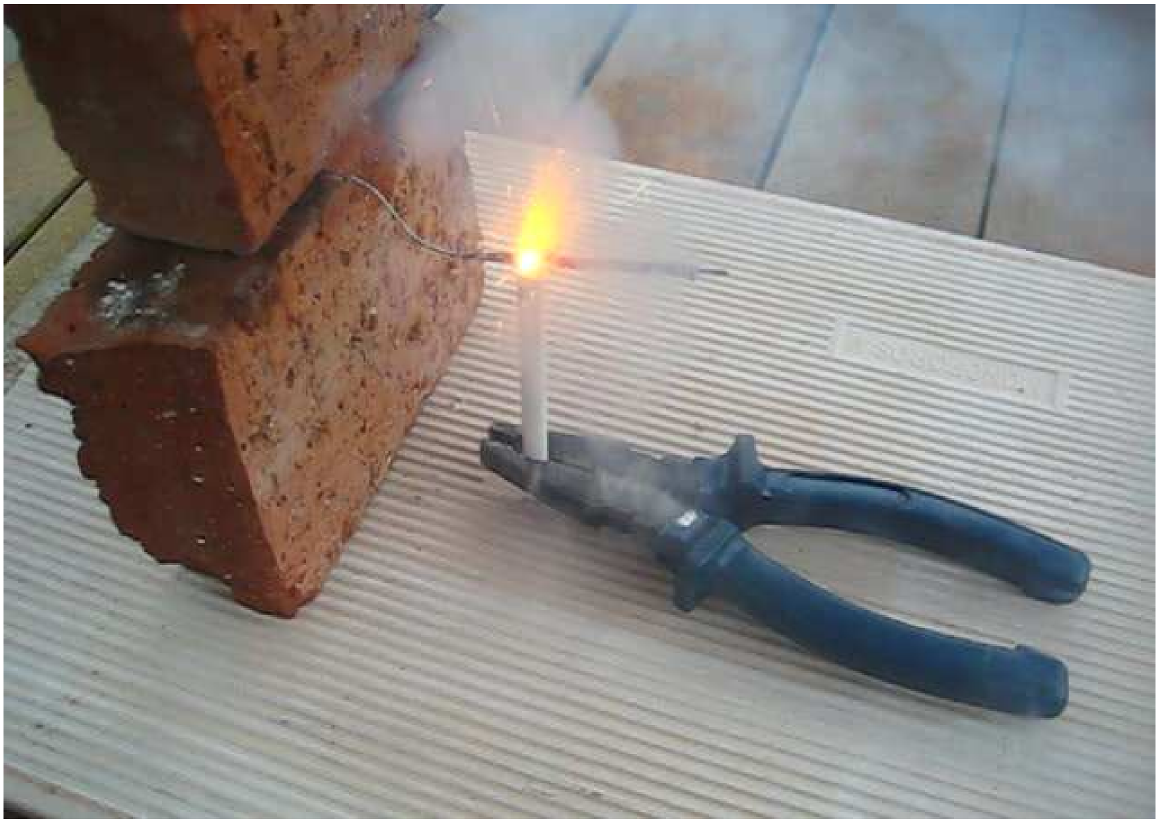

*Fig. 4 Failed strand burn test*

*Fig. 5*

*Fig. 6*

*Fig. 7*

*Fig. 8 Cast $KNO_3$-$NaNO_3$-Mannitol strand with red iron oxide additive*

*Fig. 9 Successful strand burn rate test*

**Flash freezing of the propellant**

It is desirable that the propellant has micro crystalline structure instead of a macro crystalline structure. The crystal size can be controlled by the amount of crystallization seeds and the cooling rate. A micro crystalline structure can be archived if the amount of crystallization seeds and cooling rate is high. As the solution is saturated or supersaturated and probably impure, there are enough crystallization seeds in the liquefied propellant. A high cooling rate can be easily archived by cooling the mold down to around -20ºC before pouring the liquid propellant in it.
Following experiment was conducted:

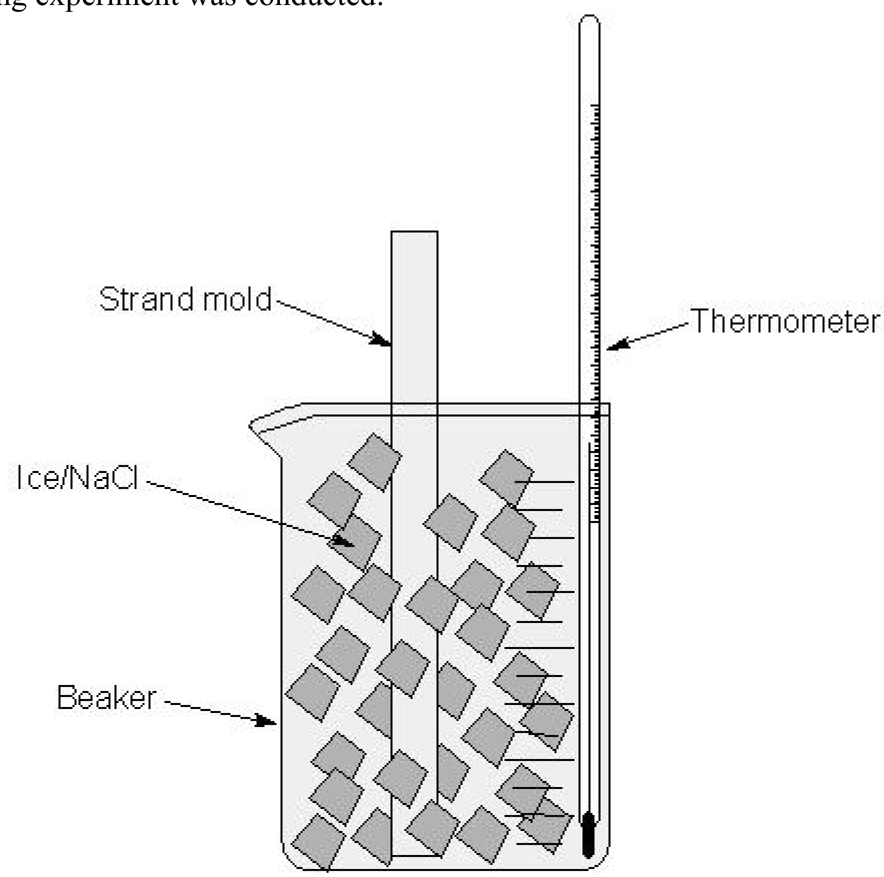


*Fig. 10 Flash freezing of the propellant*

100g ice and 23g NaCl were mixed in a beaker. (Using 100g ice and 14g $MgCl_2$ a temperature of -34ºC could be archived). The beaker with the ice/table salt mixture and strand mold was placed for one hour in the freezer compartment of the fridge, and then 10 minutes on a table at room temperature before the liquid propellant was poured into the mold.
The propellant strand was not ignitable, massive ablative behavior occurred. Further tests with larger pieces need to be done to compare burn rates.

**Calculated medium density of $KNO_3$-$NaNO_3$-Mannitol and KNSB propellant**

We are calculating the density of the mixture with following formula. (Note: the formula is only applicable if the single components are immiscible at a molecular level which applies as the solid propellant is considered as an alloy).

$$\rho_M = \frac{\sum m_i}{\sum V_i} = \frac{\sum m_i}{\sum \frac{m_i}{\rho_i}}$$

| Substance | Density at 20ºC |
|---|---|
| $KNO_3$ | 2.11 g/cm$^3$ |
| $NaNO_3$ | 2.26 g/cm$^3$ |
| Mannitol | 1.49 g/cm$^3$ |
| Sorbitol | 1.49 g/cm$^3$ |

$KNO_3$-$NaNO_3$-Mannitol/Sorbitol:

$$\rho_M = \frac{5.45g + 4.55g + 5.4g}{\frac{5.45g}{2.11g/cm^3} + \frac{4.55g}{2.26g/cm^3} + \frac{5.4g}{1.49g/cm^3}} \approx 1.8734 \frac{g}{cm^3}$$

KNSB:

$$\rho_M = \frac{65g + 35}{\frac{65g}{2.11g/cm^3} + \frac{35g}{1.49g/cm^3}} \approx 1.8418 \frac{g}{cm^3}$$

In regard of the DoubleSShot propellant mass $m_P = 90.12kg$ and considering $KNO_3$-$NaNO_3$-Mannitol and KNSB have the same performance:

$$V_1 = \frac{90120g}{1.8734g/cm^3} = 48105.04964cm^3$$

$$V_2 = \frac{90120g}{1.8418g/cm^3} = 48930.39418cm^3$$

Volume savings:

$$48930.39418cm^3 - 48105.04964cm^3 = 825.345cm^3$$

In regard of the eXSShot propellant mass $m_P = 406kg$:

$$V_1 = \frac{406000g}{1.8734g/cm^3} = 216718.23cm^3$$

$$V_2 = \frac{406000g}{1.8418g/cm^3} = 220436.53cm^3$$

Volume savings:

$$220436.53cm^3 - 216718.23cm^3 = 3718.53cm^3$$

Still not considered are the molar masses of $KNO_3$ and $NaNO_3$. $KNO_3$ has a molar mass of 101.11g/mole and $NaNO_3$ a molar mass of 84.99g/mole. In other words, 101.11g $KNO_3$ containing the same amount of oxygen than 84.99g $NaNO_3$.