

ESTIMATE ENERGY REQUIREMENT FOR PRODUCING  
KN9B PROPELLANT BY CONVENTIONAL "MIX &  
MELT" METHOD

DEC.  
2005

CONSIDER  $\Delta T = 100 \text{ K}$  (FROM  $25^\circ\text{C}$  TO  $125^\circ\text{C}$ )

FOR SORBITOL:

$$\begin{aligned}\Delta E &= \Delta H_{\text{fusion}} + C_p \Delta T \\ &= 165.8 + 1.325(100) \quad \text{KJ/Kg} \\ &= \underline{298} \text{ KJ/Kg}\end{aligned}$$

FOR  $\text{KN}_3\text{O}_3$  :  $\Delta E = C_p \Delta T$  (no phase change)

$$\begin{aligned}&= 1.00(100) \quad \text{KJ/Kg} \\ &= \underline{100} \text{ KJ/Kg}\end{aligned}$$

CONSIDER  $\text{KN}_9\text{B}$  65/35 O/F RATIO MIXTURE

$$\begin{aligned}\Delta E &= 0.35(298) + 0.65(100) \\ &= \underline{169} \text{ KJ/Kg}\end{aligned}$$

CALCULATE  $\Delta E$  IN KILOWATT-HRS. FOR ONE 34 kg SEGMENT

$$\Delta E = \frac{169}{3600} (34) = \underline{1.60} \text{ kwatt-hrs/segment}$$

NOTE THAT THIS IS THE MINIMUM ENERGY REQUIRED  
(ASSUMES FULLY ADIABATIC CONDITIONS)

## ESTIMATE ENERGY REQUIREMENT OF KRECH METHOD

- ASSUMPTION OF 11 kg H<sub>2</sub>O REQUIRED FOR ONE 34 kg SEGMENT

- 1)  $\Delta E$  REQUIRED TO RAISE 11 kg H<sub>2</sub>O FROM 300 K TO 423 K  
(27°C TO 150°C)  
AND TO FULLY EVAPORATE H<sub>2</sub>O

$$\begin{aligned}\Delta E &= m (\Delta H_{\text{VAP}} + C_p \Delta T) \\ &= 11 [2440 + 4.217 (150 - 27)] \\ &= 32550 \text{ KJ.}\end{aligned}$$

- 2)  $\Delta E$  REQUIRED TO RAISE MASSES OF SORBITOL & KNO<sub>3</sub>  
FROM 27°C TO 150°C

$$\begin{aligned}\text{MASS SORBITOL} &= 0.35 (34) = 11.9 \text{ kg} \\ \text{MASS KNO}_3 &= 0.65 (34) = 22.1 \text{ kg}\end{aligned}$$

$$\begin{aligned}\Delta E &= (m C_p \Delta T)_{\text{SORB}} + (m C_p \Delta T)_{\text{KNO}_3} \\ &= 11.9 (1.325) 123 + 22.1 (1.01) 123 \\ &= 1934 + 2745 \\ &= \underline{4679} \text{ KJ}\end{aligned}$$

- 3) TOTAL  $\Delta E$  REQUIRED

$$\begin{aligned}\Delta E_{\text{TOT}} &= 32550 + 4679 \\ &= 37229 \text{ KJ}\end{aligned}$$

CONVERT TO KILOWATT-HRS =

$$\Delta E_{\text{TOT}} = \frac{37229}{3600} = \underline{10.3} \text{ Kwatt-hrs/segment}$$

NOTE THAT THIS IS THE MINIMUM ENERGY REQUIRED  
(ASSUMES FULLY ADIABATIC CONDITIONS)

## ESTIMATE ENERGY REQUIREMENT OF KRECH/NAKKA METHOD

1)  $\Delta E$  TO HEAT UP TANKS OF SORBITOL &  $KNO_3/H_2O$  SOL'NS

$$\text{SORBITOL: } m_{\text{mass}} = 0.35(34) = 11.9 \text{ kg. } T_{\text{melt}} = 130^\circ\text{C}$$

$$\Delta H_{\text{fusion}} = 165.8 \text{ kJ/kg.}$$

$$C_p = 1.325 \text{ kJ/kg-K}$$

$$\Delta E = (\Delta H_{\text{fusion}} + C_p \Delta T) m$$

$$= [165.8 + 1.325(130 - 27)] 12$$

$$= 3627 \text{ kJ.}$$

$$\left[ \begin{array}{l} KNO_3 : m_{\text{mass}} = 0.65(34) = 22.1 \text{ kg.} \\ H_2O : m_{\text{mass}} = \frac{20}{80}(22.1) = 5.5 \text{ kg.} \end{array} \right.$$

$$T_{\text{final}} = 160^\circ\text{C} \quad \therefore \Delta T = 160 - 27 = 133 \text{ K}$$

$$\Delta E = (m C_p \Delta T)_{KNO_3} + (m C_p \Delta T)_{H_2O}$$

$$= 22.1(1.01)133 + 5.5(4.22)133$$

$$= 2969 + 3087$$

$$= 6055 \text{ kJ}$$

2)  $\Delta E$  TO EVAPORATE MASS OF  $H_2O$

$$\Delta E = \Delta H_{\text{VAP}} m$$

$$= 2440(5.5)$$

$$= 13420 \text{ kJ}$$

3) TOTAL  $\Delta E$  REQUIRED

$$\Delta E_{\text{TOT}} = 3627 + 6055 + 13420$$

$$= 23102 \text{ kJ}$$

CONVERT TO KILOWATT-HRS:

$$\Delta E_{\text{TOT}} = \frac{23102}{3600} = \underline{\underline{6.4}} \text{ kWatt-hrs/segment}$$

NOTE THAT THIS IS THE MINIMUM ENERGY REQUIRED  
(ASSUMES FULLY ADIABATIC CONDITIONS)

## APPENDIX

### THERMOCHEMICAL PROPERTIES OF SORBITOL, $\text{KNO}_3$ & $\text{H}_2\text{O}$

#### SORBITOL

$$\text{MW} = 182.17 \quad \text{g/mole}$$

$$\Delta \bar{H}_{\text{fusion}} = 30.2 \quad \text{kJ/mole} \quad [1]$$

$$\bar{C}_p = 241.43 \quad \text{J/mol-K} \quad @ 300\text{K} \quad [1]$$

$$\therefore C_p = 241.43 \frac{\text{J}}{\text{mol-K}} \frac{1 \text{ mol}}{182.17 \text{ g}} \frac{1000 \text{ g}}{\text{kg}} = 1.325 \text{ kJ/kg-K}$$

DUE TO LACK OF  $C_p$  DATA AT ELEVATED TEMPERATURE, THIS VALUE IS USED FOR PRELIMINARY ANALYSIS OVER FULL TEMPERATURE RANGE.

$$\Delta \bar{H}_{\text{fusion}} = 30.2 \frac{\text{kJ}}{\text{mole}} \frac{1 \text{ mole}}{182.17 \text{ g}} \frac{1000 \text{ g}}{\text{kg}} = 165.8 \text{ kJ/kg}$$

#### $\text{KNO}_3$

$C_p$  AS FUNCTION OF TEMPERATURE IS SHOWN IN FIGURE 1.

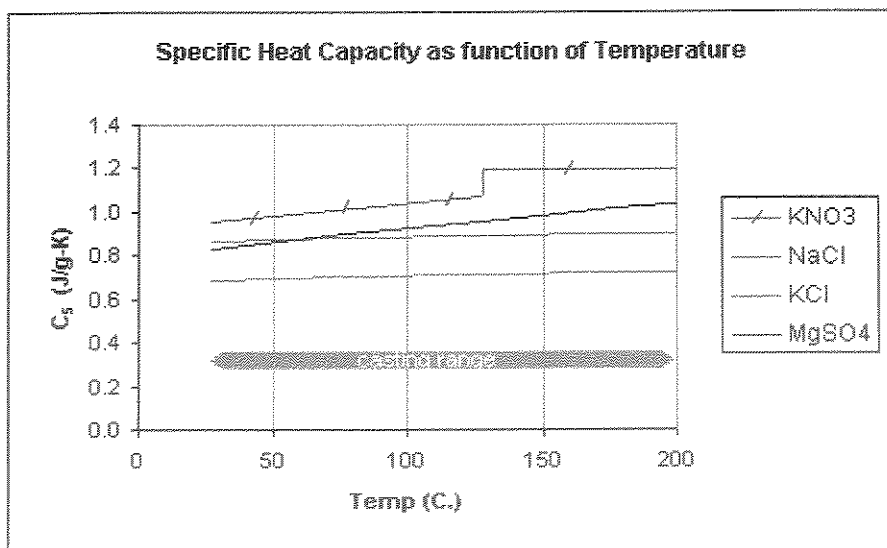
$$\text{RANGE } 250-1300: C_{p, \text{AVG}} = (0.95 + 1.06) \frac{1}{2} = 1.01 \text{ J/g-K} (= \text{kJ/kg-K})$$

$$> 130^\circ\text{C} \quad C_p = 1.2 \text{ J/g-K} (= \text{kJ/kg-K})$$

#### $\text{H}_2\text{O}$

$$\Delta H_{\text{VAP}} = 2440 \text{ kJ/kg}$$

$C_p$  AS FUNCTION OF TEMPERATURE IS SHOWN IN FIGURE 2. [1]

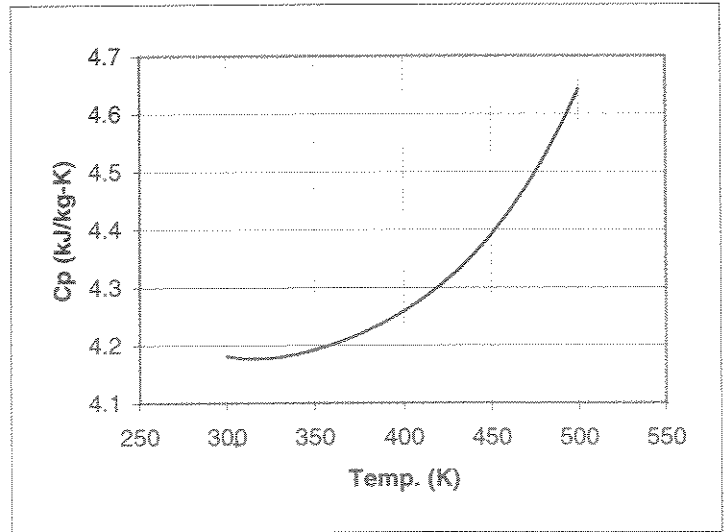


Ref. [www.nakka-rocketry.net](http://www.nakka-rocketry.net) (opinert.gif)

FIGURE 1

Heat capacity of water as function of temperature

Temp. K	Temp. C	t K/1000	Cp J/mol-K	Cp kJ/kg-K	Cpavg [1] kJ/kg-K
300	27	0.3	75.351	4.182	4.182
310	37	0.31	75.273	4.177	4.179
320	47	0.32	75.267	4.177	4.179
330	57	0.33	75.317	4.180	4.179
340	67	0.34	75.414	4.185	4.180
350	77	0.35	75.549	4.193	4.182
360	87	0.36	75.719	4.202	4.185
370	97	0.37	75.923	4.213	4.188
380	107	0.38	76.159	4.226	4.193
390	117	0.39	76.432	4.242	4.198
400	127	0.4	76.745	4.259	4.203
410	137	0.41	77.103	4.279	4.209
420	147	0.42	77.512	4.301	4.217
430	157	0.43	77.979	4.327	4.224
440	167	0.44	78.514	4.357	4.233
450	177	0.45	79.124	4.391	4.243
460	187	0.46	79.820	4.430	4.254
470	197	0.47	80.611	4.473	4.266
480	207	0.48	81.508	4.523	4.280
490	217	0.49	82.522	4.579	4.295
500	227	0.5	83.664	4.643	4.311



Ref: <http://webbook.nist.gov/cgi/cbook.cgi?Name=water&Units=SI&cTC=on>

[1] Average Cp in range from 300K to given temperature

FIGURE 2