
# *Eutectic Sugar Propellant Research, Part III*

Rev. 2011/09/21

**Characteristics of D-mannitol**

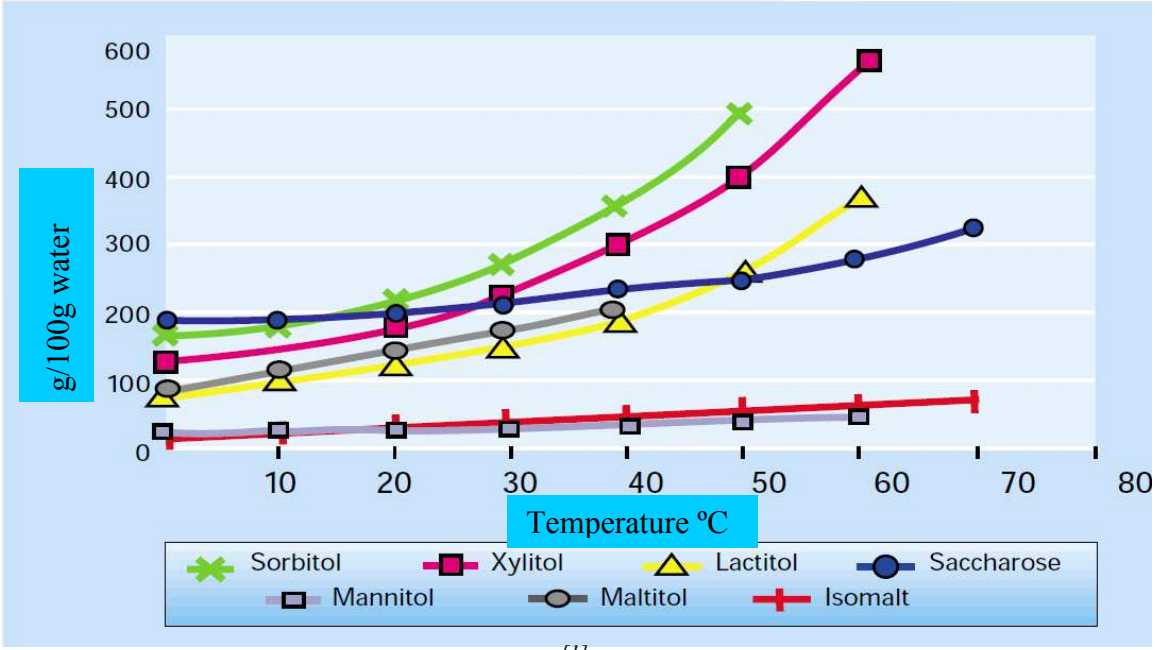



*Fig. 1 Solubility of sugar alcohols in water* [1]

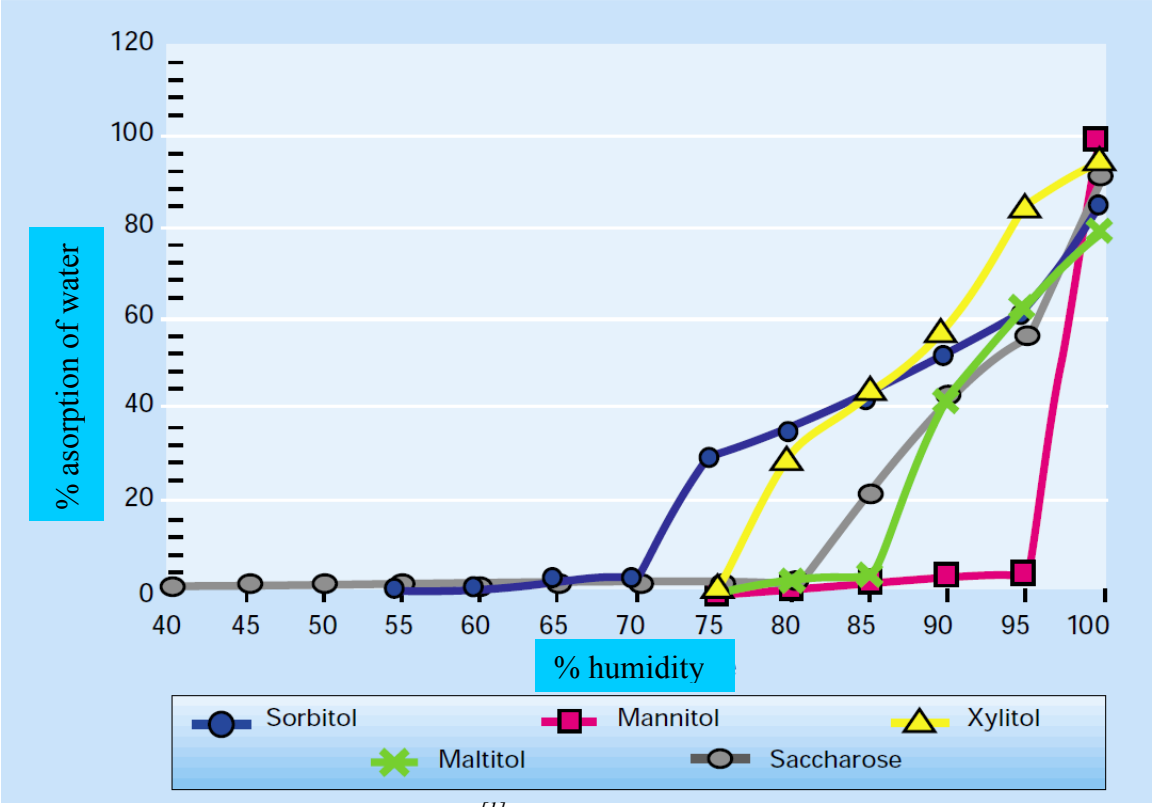
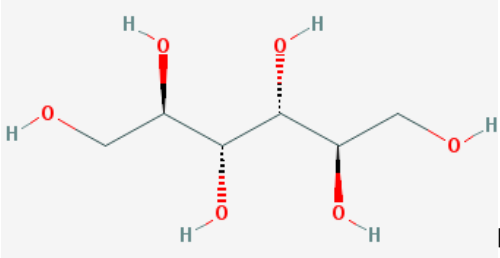



*Fig. 2 Hygroscopy of sugar alcohols* [1]

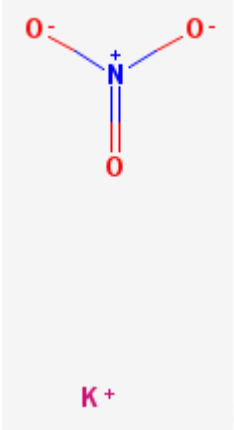
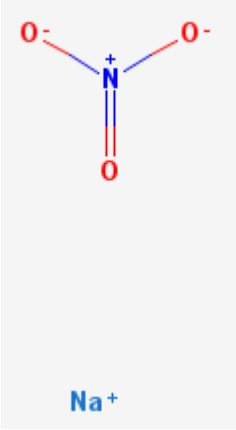
Molecular Formula: $C_6H_{14}O_6$ [2]
Molar mass: 182.17 g/mol [2]



[3]

2-D structure:
CAS-No.: 69-65-8 [2]
Ignition temperature: 410 °C [2]
Melting point: 164 - 169 °C [2]
Boiling point: 290 - 295 °C (4 hPa) [2]
Density: 1.49 g/cm$^3$ (20 °C) [2]
Bulk density: 400 - 500 kg/m$^3$ [2]
pH value: 5 - 7 (100 g/l, $H_2O$, 20 °C) [2]
Food energy: (240 kcal/ 1004kJ)/100 g [4]

**Characteristics of $KNO_3$ and $NaNO_3$**

| Formula | $KNO_3$ | $NaNO_3$ |
|---|---|---|
| Molar mass | 101.10 g/ mole [7] | 84.99 g/mole [7] |
| Density | 2.11 g/cm$^3$ (20 °C) [7] | 2.26 g/cm$^3$ (20 °C) [7] |
| Melting point | 334 °C [7] | 308 °C [7] |
| Boiling point | 400°C (decomposition) [5] | 380°C (decomposition) [6] |
| Bulk density | 800 kg/m$^3$ [7] | 1200 kg/m$^3$ [7] |
| pH value | 5.0 - 7.5 (50 g/l, $H_2O$, 20 °C) [7] | 5.5 - 8.0 (50 g/l, $H_2O$, 20 °C) [7] |
| 2-D structure |  [3] |  [3] |

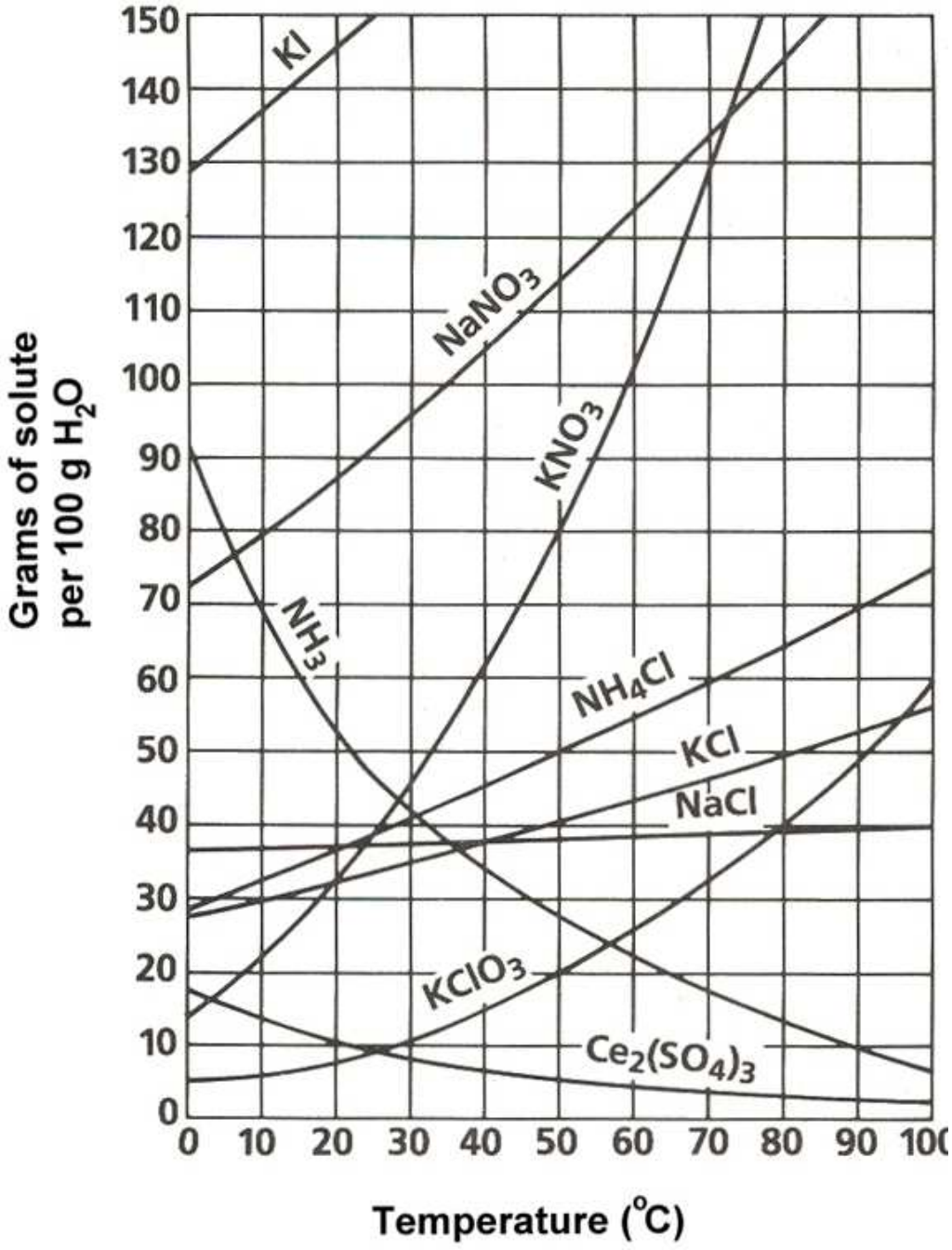



*Fig. 3 Solubility of KNO3, NaNO3 and other salts in water* [8]

**Some interesting GUIPEP outputs**

GUIPEP: $KNO_3$/$NaNO_3$/mannitol, ratio 35:30:35

```
  CODE                                  WEIGHT    D-H  DENS      COMPOSITION
   821 POTASSIUM NITRATE                35.000  -1169  0.07670    1N   3O   1K
   886 SODIUM NITRATE                   30.000  -1312  0.08160    1N   3O   1NA
  1087 MANNITOL                         35.000  -1756  0.05490    6C  14H   6O

THE PROPELLANT DENSITY IS 0.06842 LB/CU-IN OR  1.8939 GM/CC
THE TOTAL PROPELLANT WEIGHT IS  100.0000 GRAMS

NUMBER OF GRAM ATOMS OF EACH ELEMENT PRESENT IN INGREDIENTS

   2.689677 H     1.152719 C     0.699110 N     3.250048 O
   0.352945 NA    0.346164 K

****************************CHAMBER RESULTS FOLLOW
******************************

 T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY   CP/CV     GAS   RT/V
1731. 2657.   68.02  1000.00  -141.74   176.85  1.1345  2.545   26.727

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL=   10.698   14.858
NUMBER MOLS GAS AND CONDENSED=   2.5451   0.3263

  1.00801 H2O         0.43340 CO          0.39301 CO2         0.34947 N2
  0.31470 H2          0.17259 Na2CO3*     0.15364 K2CO3*      0.03675 KHO
 6.59E-03 NaHO       1.64E-03 K          1.09E-03 Na         2.28E-04 K2H2O2
 9.62E-05 NH3        2.13E-05 H          2.00E-05 NaH        1.83E-05 Na2H2O2
 1.43E-05 KH         6.62E-06 KCN        3.91E-06 HO         3.74E-06 NaCN
 3.56E-06 CH4        2.65E-06 CH2O       2.10E-06 CNH

THE MOLECULAR WEIGHT OF THE MIXTURE IS   34.826

****************************EXHAUST RESULTS FOLLOW
******************************

 T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY   CP/CV     GAS   RT/V
1135. 1584.    1.00    14.70  -171.42   176.85  1.1387  2.498    0.400

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL=    9.784   14.313
NUMBER MOLS GAS AND CONDENSED=   2.4981   0.3492

  0.88960 H2O         0.50869 CO2         0.45487 H2          0.34952 N2
  0.29474 CO          0.17643 Na2CO3*     0.17278 K2CO3&      0.00055 KHO
 3.84E-05 NaHO       2.08E-05 K          1.92E-05 NH3        9.87E-06 Na
 7.45E-06 CH4

THE MOLECULAR WEIGHT OF THE MIXTURE IS   35.120

**********PERFORMANCE:  FROZEN ON FIRST LINE, SHIFTING ON SECOND LINE**********

IMPULSE   IS EX      T*      P*      C*    ISP*  OPT-EX  D-ISP      A*M   EX-T
  158.7  1.1398   1618.   39.21  3114.7           10.05  300.5  0.09683  1032.
  160.7  1.1158   1641.   39.55  3160.1   120.2   10.56  304.4  0.09824  1135.
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GUIPEP: $KNO_3/NaNO_3$/sorbitol, ratio 35:30:35

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  CODE                                  WEIGHT    D-H  DENS      COMPOSITION
   821 POTASSIUM NITRATE                35.000  -1169  0.07670    1N   3O   1K
   886 SODIUM NITRATE                   30.000  -1312  0.08160    1N   3O   1NA
  1093 SORBITOL                         35.000  -1776  0.05310    6C  14H   6O

THE PROPELLANT DENSITY IS 0.06743 LB/CU-IN OR  1.8663 GM/CC
THE TOTAL PROPELLANT WEIGHT IS  100.0000 GRAMS

NUMBER OF GRAM ATOMS OF EACH ELEMENT PRESENT IN INGREDIENTS

   2.689677 H     1.152719 C     0.699110 N     3.250048 O
   0.352945 NA    0.346164 K

****************************CHAMBER RESULTS FOLLOW
*****************************

 T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY   CP/CV     GAS   RT/V
1720. 2637.   68.02  1000.00  -142.43   176.44  1.1342  2.541   26.774

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL=   10.680   14.874
NUMBER MOLS GAS AND CONDENSED=   2.5407   0.3284

  1.00772 H2O        0.43127 CO         0.39299 CO2        0.34947 N2
  0.31698 H2         0.17299 Na2CO3*    0.15539 K2CO3*     0.03348 KHO
 5.92E-03 NaHO      1.45E-03 K         9.62E-04 Na        2.06E-04 K2H2O2
 9.98E-05 NH3       1.94E-05 H         1.76E-05 NaH       1.63E-05 Na2H2O2
 1.25E-05 KH        6.28E-06 KCN       4.01E-06 CH4       3.53E-06 NaCN
 3.43E-06 HO        2.68E-06 CH2O      2.12E-06 CNH

THE MOLECULAR WEIGHT OF THE MIXTURE IS   34.854

****************************EXHAUST RESULTS FOLLOW
*****************************

 T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY   CP/CV     GAS   RT/V
1125. 1565.    1.00    14.70  -171.88   176.44  1.1390  2.498   0.400

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL=    9.767   14.284
NUMBER MOLS GAS AND CONDENSED=   2.4980   0.3493

  0.88586 H2O        0.51242 CO2        0.45867 H2         0.34952 N2
  0.29094 CO         0.17644 Na2CO3*    0.17285 K2CO3&     0.00043 KHO
 2.96E-05 NaHO      2.05E-05 NH3       1.53E-05 K         9.46E-06 CH4
 7.27E-06 Na

THE MOLECULAR WEIGHT OF THE MIXTURE IS   35.121

**********PERFORMANCE:  FROZEN ON FIRST LINE, SHIFTING ON SECOND LINE**********

IMPULSE   IS EX      T*      P*      C*    ISP*  OPT-EX  D-ISP      A*M   EX-T
  158.1  1.1395   1608.   39.22  3102.6           10.06  295.0  0.09645  1026.
  160.1  1.1159   1630.   39.55  3147.5   119.7   10.55  298.7  0.09785  1125.
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GUIPEP: $KNO_3$/mannitol, ratio 65:35

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  CODE                                  WEIGHT    D-H  DENS      COMPOSITION
   821 POTASSIUM NITRATE                65.000  -1169  0.07670    1N   3O   1K
  1087 MANNITOL                         35.000  -1756  0.05490    6C  14H   6O

THE PROPELLANT DENSITY IS 0.06734 LB/CU-IN OR  1.8640 GM/CC
THE TOTAL PROPELLANT WEIGHT IS  100.0000 GRAMS

NUMBER OF GRAM ATOMS OF EACH ELEMENT PRESENT IN INGREDIENTS

   2.689677 H     1.152719 C     0.642877 N     3.081349 O
   0.642877 K

****************************CHAMBER RESULTS FOLLOW
******************************

 T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY   CP/CV     GAS   RT/V
1614. 2446.   68.02  1000.00  -137.45   169.03  1.1363  2.511   27.094

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL=   10.319   14.723
NUMBER MOLS GAS AND CONDENSED=   2.5107   0.3148

  0.92910 H2O        0.48061 CO         0.40900 H2         0.35719 CO2
  0.32132 N2         0.31482 K2CO3*     0.01259 KHO        0.00049 K
 1.83E-04 NH3       7.09E-05 K2H2O2    3.02E-05 CH4       7.77E-06 H
 6.21E-06 KCN       4.10E-06 KH        4.10E-06 CH2O      3.68E-06 CNH
 1.00E-06 NO2

THE MOLECULAR WEIGHT OF THE MIXTURE IS   35.392

****************************EXHAUST RESULTS FOLLOW
******************************

 T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY   CP/CV     GAS   RT/V
1043. 1419.    1.00    14.70  -164.70   169.03  1.1480  2.497    0.400

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL=    9.478   13.657
NUMBER MOLS GAS AND CONDENSED=   2.4972   0.3214

  0.77095 H2O        0.57347 H2         0.51497 CO2        0.32140 K2CO3&
  0.32139 N2         0.31614 CO         0.00015 CH4        0.00005 KHO
 4.37E-05 NH3       1.23E-06 K         1.00E-06 NO2

THE MOLECULAR WEIGHT OF THE MIXTURE IS   35.478

**********PERFORMANCE:  FROZEN ON FIRST LINE, SHIFTING ON SECOND LINE**********

IMPULSE   IS EX      T*      P*      C*    ISP*  OPT-EX  D-ISP      A*M    EX-T
  152.0  1.1418   1507.   39.18  2985.4           10.01  283.3  0.09281   956.
  154.0  1.1285   1518.   39.37  3006.3   115.0   10.65  287.1  0.09346  1043.
```

GUIPEP: $KNO_3$/sorbitol, ratio 65:35

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  CODE                                  WEIGHT    D-H  DENS      COMPOSITION
   821 POTASSIUM NITRATE                65.000  -1169  0.07670    1N   3O   1K
  1093 SORBITOL                         35.000  -1776  0.05310    6C  14H   6O

THE PROPELLANT DENSITY IS 0.06638 LB/CU-IN OR  1.8373 GM/CC
THE TOTAL PROPELLANT WEIGHT IS  100.0000 GRAMS

NUMBER OF GRAM ATOMS OF EACH ELEMENT PRESENT IN INGREDIENTS

   2.689677 H     1.152719 C     0.642877 N     3.081349 O
   0.642877 K

****************************CHAMBER RESULTS FOLLOW
*****************************

 T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY   CP/CV     GAS   RT/V
1600. 2421.   68.02  1000.00  -138.15   168.59  1.1362  2.509   27.114

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL=   10.300   14.720
NUMBER MOLS GAS AND CONDENSED=   2.5088   0.3157

  0.92723 H2O        0.47791 CO         0.41171 H2         0.35899 CO2
  0.32131 N2         0.31572 K2CO3*     0.01088 KHO        0.00040 K
 1.92E-04 NH3       6.02E-05 K2H2O2    3.57E-05 CH4       6.72E-06 H
 5.69E-06 KCN       4.14E-06 CH2O      3.72E-06 CNH       3.34E-06 KH
 1.00E-06 NO2

THE MOLECULAR WEIGHT OF THE MIXTURE IS   35.404

****************************EXHAUST RESULTS FOLLOW
*****************************

 T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY   CP/CV     GAS   RT/V
1033. 1399.    1.00    14.70  -165.15   168.59  1.1485  2.497   0.400

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL=    9.462   13.615
NUMBER MOLS GAS AND CONDENSED=   2.4971   0.3214

  0.76598 H2O        0.57834 H2         0.51999 CO2        0.32141 K2CO3&
  0.32139 N2         0.31106 CO         0.00020 CH4        0.00005 NH3
 3.62E-05 KHO       1.00E-06 NO2

THE MOLECULAR WEIGHT OF THE MIXTURE IS   35.480

**********PERFORMANCE:  FROZEN ON FIRST LINE, SHIFTING ON SECOND LINE**********

IMPULSE   IS EX      T*      P*      C*    ISP*  OPT-EX  D-ISP      A*M   EX-T
  151.3  1.1418   1494.   39.19  2971.3           10.01  277.9  0.09237   948.
  153.3  1.1120   1517.   39.60  3034.3   114.8   10.49  281.7  0.09433  1033.
```

GUIPEP: $NaNO_3$/mannitol, ratio 65:35

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  CODE                                    WEIGHT    D-H  DENS      COMPOSITION
   886 SODIUM NITRATE                     65.000  -1312  0.08160    1N   3O   1NA
  1087 MANNITOL                           35.000  -1756  0.05490    6C  14H   6O

THE PROPELLANT DENSITY IS 0.06973 LB/CU-IN OR  1.9301 GM/CC
THE TOTAL PROPELLANT WEIGHT IS  100.0000 GRAMS

NUMBER OF GRAM ATOMS OF EACH ELEMENT PRESENT IN INGREDIENTS

   2.689677 H     1.152719 C     0.764715 N     3.446863 O
   0.764715 NA

*****************************CHAMBER RESULTS FOLLOW
*****************************

 T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY   CP/CV     GAS   RT/V
1912. 2982.   68.02  1000.00  -146.74   185.35  1.1272  2.538   26.807

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL=   11.111   15.397
NUMBER MOLS GAS AND CONDENSED=   2.5375   0.3637

  1.10766 H2O        0.42743 CO2        0.38231 N2         0.36370 Na2CO3*
  0.36153 CO         0.22118 H2         0.03141 NaHO       0.00557 Na
 1.02E-04 Na2H2O2   9.61E-05 NaH       7.89E-05 H         4.13E-05 NH3
 3.40E-05 HO        5.07E-06 Na2       4.07E-06 NaCN      1.45E-06 CH2O
 1.34E-06 NO

THE MOLECULAR WEIGHT OF THE MIXTURE IS   34.468

*****************************EXHAUST RESULTS FOLLOW
*****************************

 T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY   CP/CV     GAS   RT/V
1233. 1759.    1.00    14.70  -179.48   185.35  1.1317  2.498   0.400

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL=   10.141   14.805
NUMBER MOLS GAS AND CONDENSED=   2.4980   0.3821

  1.01248 H2O        0.51707 CO2        0.38233 N2         0.38211 Na2CO3*
  0.33215 H2         0.25348 CO         0.00035 NaHO       0.00011 Na
 7.86E-06 NH3

THE MOLECULAR WEIGHT OF THE MIXTURE IS   34.720

**********PERFORMANCE:  FROZEN ON FIRST LINE, SHIFTING ON SECOND LINE**********

IMPULSE   IS EX      T*      P*      C*    ISP*  OPT-EX  D-ISP      A*M   EX-T
  167.5  1.1319   1794.   39.32  3277.3           10.23  323.2  0.10189  1169.
  168.8  1.1193   1810.   39.50  3299.5   126.0   10.46  325.8  0.10258  1233.
```

**Casting of the forward/aft chamber propellant at once**

The eutectic method allows to just mechanical mix (without milling) $KNO_3$, $NaNO_3$ and mannitol, pour in the mixture in the mold and heat the mold then up to the required temperature, which completely liquefy the propellant. Containing water will be removed during the heat build-up, remaining air will ascend in the liquid propellant, which has a viscosity nearly like water.
To heat up such a long mold, a special oven like used in industry, is needed.

*Fig. 4 Example of a suitable industrial oven from france-etuves.com. Temperature spatial variation: less than ±1,2°C at 105°C and less than ±2,5°C at 200°C. The oven is available with an internal height of 500mm to 1800mm and max. temperature up to 300°C [9]*

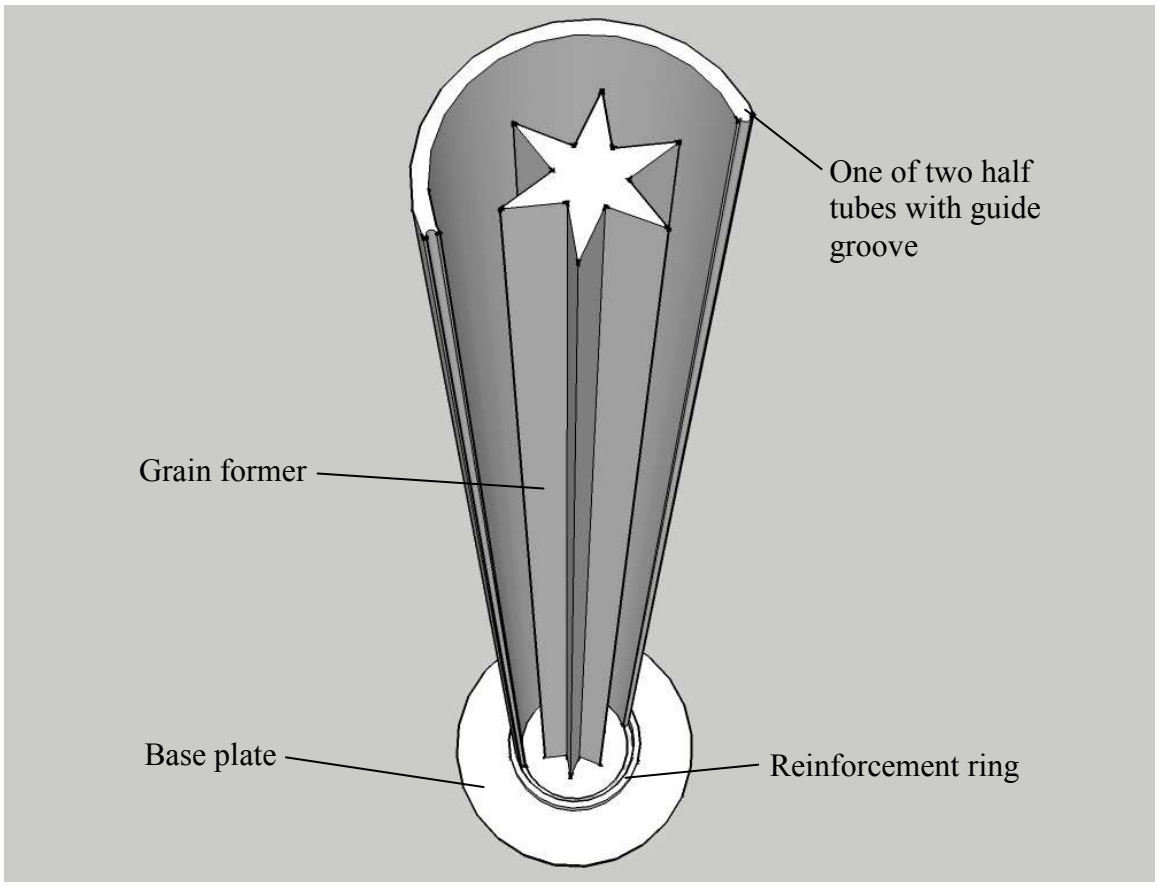


*Fig. 5 Construction of the mold*

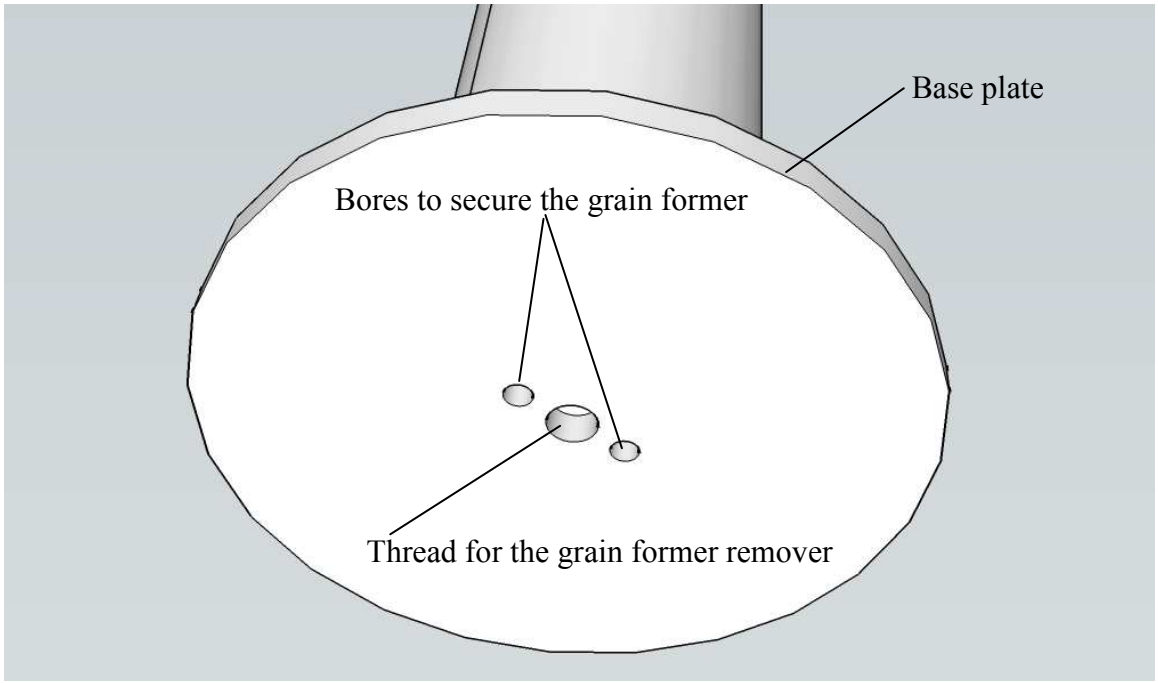


*Fig. 6 Base plate*

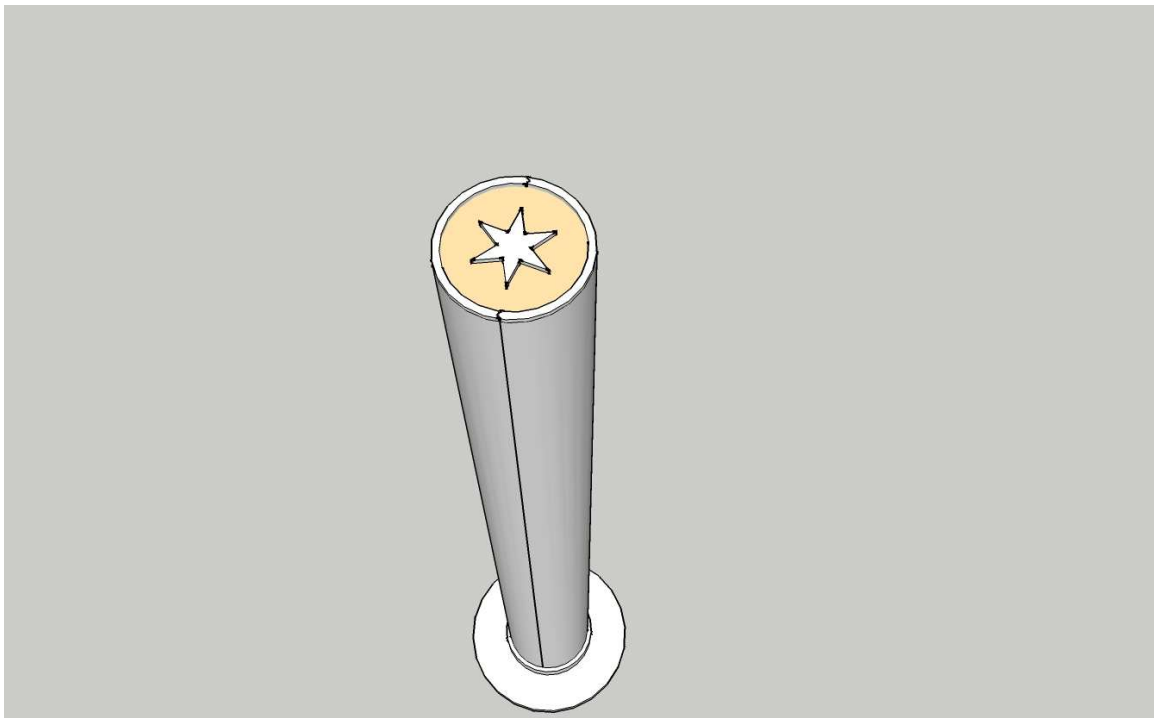

*Fig. 7 Mold with cured propellant*

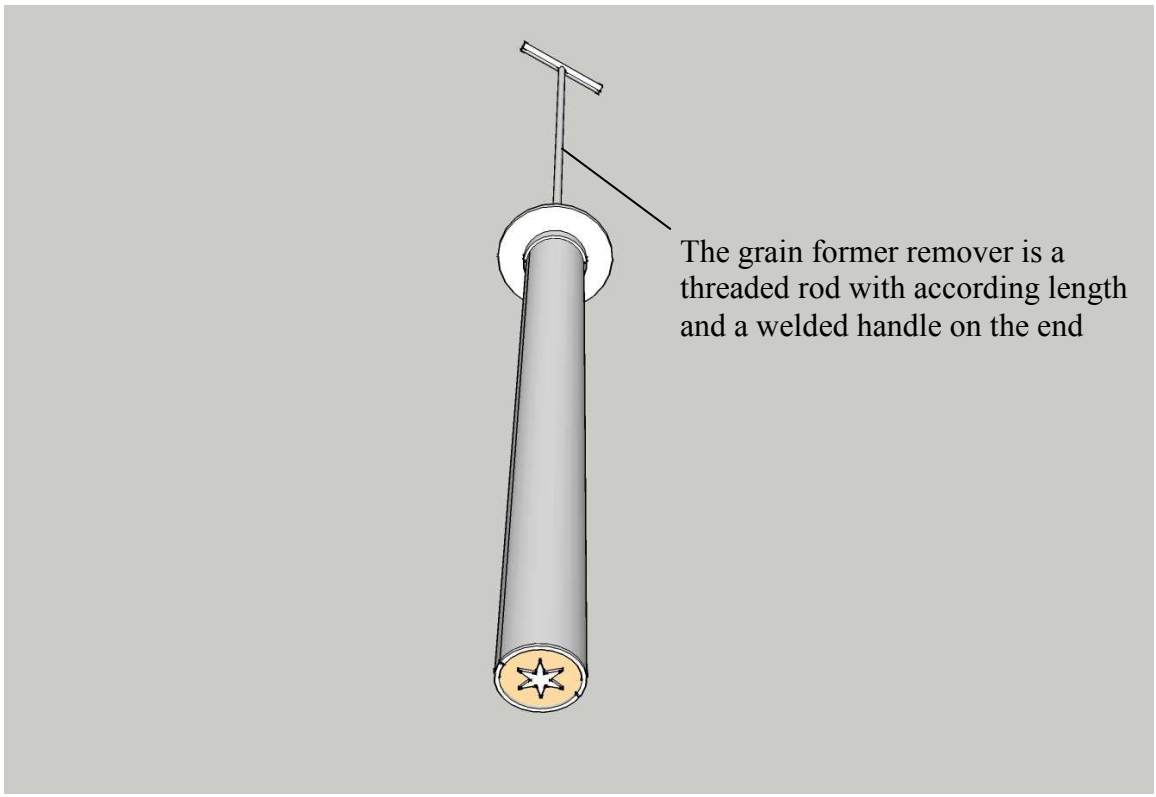


*Fig. 8 Grain former remover applied*

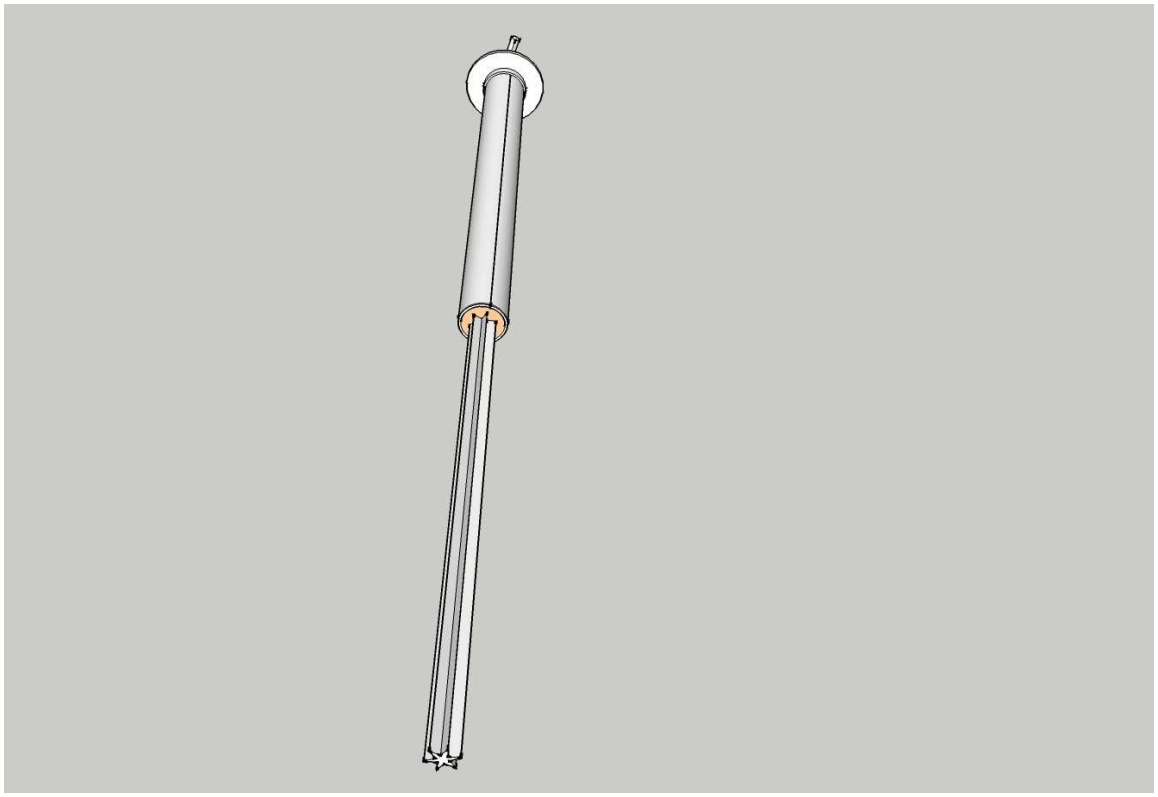

*Fig. 9 Grain former removed*

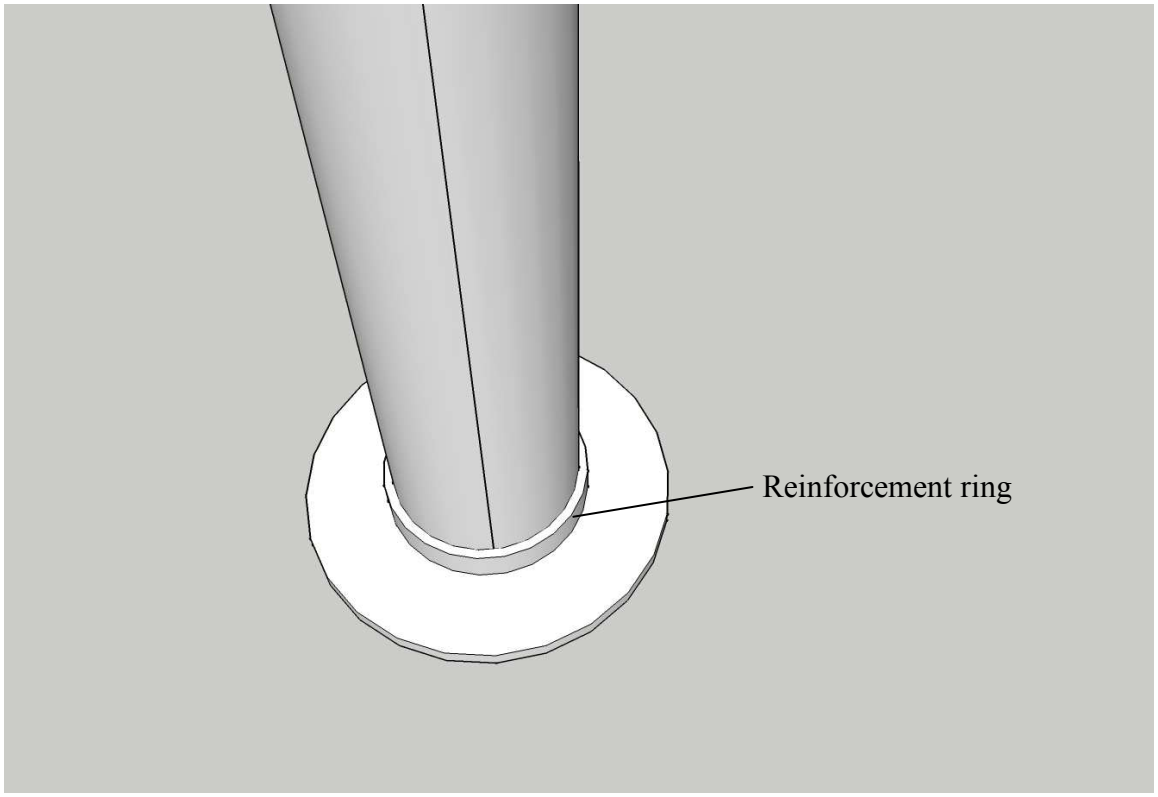


*Fig. 10 Removing the reinforcement ring*

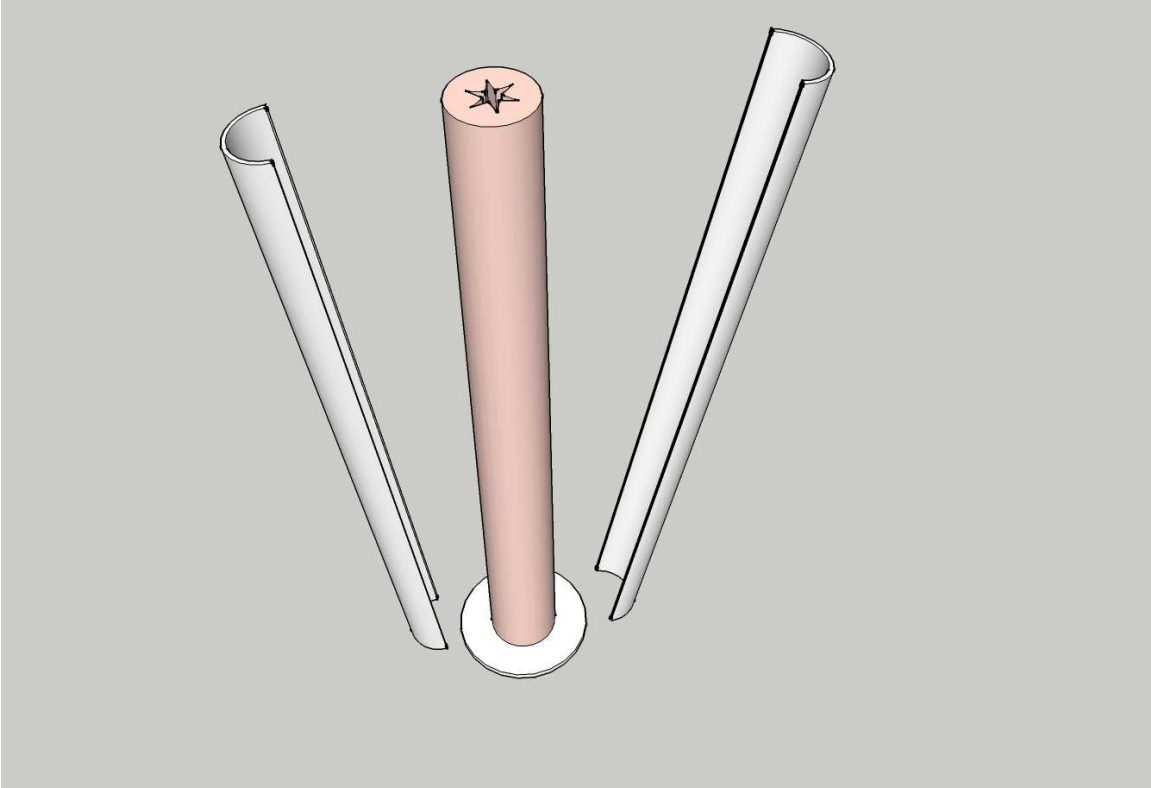

*Fig. 11 Removing the two half tubes*

**References**


[1] http://www.dhw-ecogreenoleo.de/Zuckeralkohole.pdf

[2] http://www.merck-chemicals.com/germany/d-mannit/MDA_CHEM-105303/p_HtOb.s1L150AAAEWIuEfVhTl

[3] http://pubchem.ncbi.nlm.nih.gov/

[4] http://www.gesundheitstrends.de/ernaehrung/lexikon/zucker.php

[5] http://www.safewater.org/PDFS/owd/Potassium_Nitrate_MSDS.pdf

[6] http://www.sciencelab.com/msds.php?msdsId=9927271

[7] http://www.merck-chemicals.de/

[8] http://www.saskschools.ca/curr_content/chem30_05/graphics/4_graphics/sol_curve.jpg

[9] http://france-etuves.com/PDF/PRODUCTS/FRANCE-ETUVES-XL.pdf