# An Introduction to PROPEP, A Propellant Evaluation Program for Personal Computers

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***ABSTRACT***

*Propellant evaluation programs are used to estimate the performance of rocket propellants, to compare the performance of different propellants, and to evaluate the effects of formulation changes. While the program output may not be exact, it compares well with experimental results. Their major weakness lies in the accuracy and completeness of the underlying thermochemical database used for calculations. These programs are potentially useful for the evaluation of non-rocket chemical equilibrium. This article provides a guide to installing, testing and using* ***PROPEP****, a propellant evaluation program available in the public domain. Some basic knowledge of computer terminology, chemistry, etc. is required.*

**Keywords:** chemical equilibrium, PEP, propellant, rocket, thermodynamics, evaluation

## Introduction

**PEP** is an acronym for Propellant Evaluation Program. **MICROPEP** and **PROPEP** are Personal Computer (IBM PC or compatible) versions of **PEP** and **NEWPEP**, which were written at the Naval Weapons Center, China Lake, CA. **MICROPEP** was the original program released by Larry Williams and John Cunningham of Martin Marietta. **MICROPEP** had several quirks and preferred to run on a "clean" system. **PROPEP** reduced or eliminated **MICROPEP**'s problems and added improvements. Both programs were developed by employees of Martin Marietta and made available for public use. There is no support and there are no warranties for these programs. Anyone using **PROPEP** must form their own opinion concerning its suitability and accuracy for their application.

There are other programs written to perform thermodynamic calculations on propellant and explosive formulations, including **NASA/Lewis**, **BLAKE**, **TIGER**, etc. However, **PROPEP** has several advantages. It is available in the public domain, and it runs on PC's with a math coprocessor. The source code and data files are included on the distribution disks; so they can be studied or modified. The program is simple to use and produces usable data. Last, but not least, **PROPEP** is "free."

**PROPEP** also has drawbacks. Understanding and using its capabilities and output may not be as easy as users would like. It sometimes "bombs" out or gives "bad" results, for example, with a mixture of zinc and sulfur. This is because the thermochemical data for the possible reaction products (in all possible physical states) are not included in **PROPEP**'s **JANNAF.DAF** file. This file contains thermochemical data (from several sources) for program use. If the **PROPEP** output has question marks or error messages, the results may be incorrect. Also, if necessary reaction product information is not available, **PROPEP** will produce incorrect results. Much like humans, the program makes the best estimates it can, based on its knowledge base. Users must form their own opinion about the accuracy of output for their applications. **PROPEP** dislikes small quantities (less than 0.5%) of any ingredient. It attempts to do what it is told to do, rather than what might be wanted. The other **PEP** programs share many, if not all, of these drawbacks. All programs of this type must make simplifying assumptions. Sutton[1] presents a good introduction to the basic methods used for thermodynamic calculations, and he explains some of these assumptions.

**PROPEP** can also be used to improve one's understanding of propellant combustion. For example, **PROPEP** can be used to compare propellants and to evaluate the effects of formulation

changes. Using **PROPEP,** initial evaluations of propellants can be made without physically preparing and testing each formulation. This can save time, work, material, and expense. **PROPEP** calculates density, temperatures, molecular weights, reaction product information, exhaust velocity, specific impulse, specific heat values, etc. It does not, however, provide burn rate versus pressure information; the author is unaware of a program with this capability.

## System Information

**MICROPEP** would not run on the author's PC with a 286 central processing unit (CPU) until a math coprocessor was installed. A math coprocessor is also needed to run **PROPEP**. The suggested minimum configuration is a PC with a 286 CPU and a math coprocessor. A PC with a 486 CPU (and a math coprocessor) is much faster; a Pentium CPU should be even better.

## Program Information

**PROPEP** originally was distributed on two 5.25" 1.2M floppy disks but will fit on a single 3.5" 1.44M disk.

Disk 1 contained the following files:

**READ.ME –** preliminary information**,**

**PROPEP.TXT** – brief instructions for using the program**,**

**PROPEP.EXE** – the executable program**,**

**PEPCODED.DAF** – the ingredient file**,**

**JANNAF.DAF** – reaction product information used by the program**,**

**SETUP.PEP** – file telling the program where to find the files it needs**,**

**INPUT.DAT** – a sample input file, and

**SAMPLE.CHK** – output file for sample input file**.**

Disk 2 contained:

**PROPEP.FOR** – FORTRAN source code for the main program,

**JANCREAT.FOR** – FORTRAN source code used to create **JANNAF.DAF**, and

**JANINPUT.DAT** – input information needed for **JANCREAT.FOR**.

## Installation and Test

As always, make backup copies of program disk(s) and store original disk(s) in a safe place. Unless the user is a programmer with access to a FORTRAN compiler, the files listed as being on Disk 2 are not needed.

The author recommends installation of **PROPEP** on a PC's hard drive. Prior to installation, a directory for the **PROPEP** files must be created. **PEP** is the suggested directory name. Any name can be used, but the user will need to modify the **SETUP.PEP** file for any directory name other than **PEP**. The setup file uses **PEP** as the directory name with the program installed on the C drive. Copy all files, listed on Disk 1, to the **PEP** directory. Make backup copies of the files **INPUT.DAT**, **PEPCODED.DAF**, and **SETUP.PEP**. by using the same filenames, but using the extension of "**.BAC**" for the backup copies. **PROPEP** is sensitive to field lengths, etc. Thus, if mistakes are made during changes to files, it is convenient to have backup files available. After changes have been made and the program works correctly, update the backup files for future use.

**EDIT** is an **ASCII** editor provided in **MS-DOS** versions 5 and 6. It can be used to make changes to **SETUP.PEP**. These changes are needed before **PROPEP** can be run (changes are explained below). Other **ASCII** editors may be used but make sure **PROPEP** can read their output by testing with the sample files.

Print the following files for future reference:

**READ.ME** – one page,
**PROPEP.TXT** – about five pages,
**INPUT.DAT** – one page,
**SAMPLE.CHK** – one page, and
**SETUP.PEP** – one page.

The author also printed out **PEPCODED.DAF** (about 34 pages). Some users may find it easier to scan a written copy than to use the monitor screen, while others may prefer to use their editor's search function to find ingredients. Print at least the first page of **PEPCODED.DAF** as this page has information on the format for the in-

gredient information. **PEPCODED.DAF** contains 1092 lines. The information provided in **PEPCODED.DAF** and this article should function as a program manual.

Edit the **SETUP.PEP** file to tell **PROPEP** where to find the files it needs (An example follows.). If **PROPEP** will be operated from the PC's hard disk or from a single high density (**HD**) floppy disk, Line 1 should contain "**HD**." Line 2 contains the full path to the file – **PEPCODED.DAF**. Line 3 is not used by **PROPEP**, but must have something in it anyway. (See below.) Line 4 is the full path to the reaction product file. Line 5 is the location of the default output file. If these files were placed in a directory other than **PEP**, change these lines to reflect the directory used. The file, **SETUP.PEP**, should now look like the following if **PROPEP** is executed from the **PEP** directory on the **C**: drive:

- **HD**
- **C:\PEP\PEPCODED.DAF**
- **C:\PEP\NOTUSED**
- **C:\PEP\JANNAF.DAT**
- **C:\PEP\PROPEP.OUT**

When satisfied with **SETUP.PEP**, save it and exit the editor.

As a test, run the sample data provided in **INPUT.DAT**. First, change to the **PEP** directory; then type "**PROPEP,**" and press Enter. Introductory information about the program is displayed along with the message "**CARRIAGE RETURN TO CONTINUE**." After the carriage return (Enter key) is pressed, information is displayed about the ingredients being considered. The case being run and the starting time are also displayed. When the calculations are complete, "**EXECUTION TERMINATED: 0**" appears on the screen, and the DOS prompt is displayed. Print the **SAMPLE.OUT** file and compare it with a printout of the **SAMPLE.CHK** file. (See Figure 1 for an example of typical **PROPEP** results.) If they are identical, other evaluations may be run. A very minor bug in the program is that there are four unneeded spaces after "**CHAMBER RESULTS FOLLOW**" and "**EXHAUST RESULTS FOLLOW**" in the output file. If desired, these spaces can be edited out before printing. The sample run is a single set of calculations using liquid oxygen and hydrogen in a rocket engine. The engine operates at a chamber pressure of 1000 psia (6.89 MPa) and exhausts to a pressure of 14.7 psia (101 kPa). ("psia" is absolute pressure in pounds per square inch.)

## PROPEP – Application and Demonstration

Much research has been done on black powder in the last twenty years. One suggestion from this research[2,3] was to substitute phenolphthalein for charcoal. The goal of this substitution was the production of a "good" black powder with less lot-to-lot variation than conventional Black Powder. This is because phenolphthalein is a well characterized material, while charcoal has many uncontrollable variables in its composition. How do the **PROPEP** results for a black powder made with charcoal compare with results for a black powder made with phenolphthalein?

Charcoal and phenolphthalein are not contained in the ingredient file, **PEPCODED.DAF**, However, the information is available.[2–4] One formulation for charcoal is $C_{322}H_{184}NO_{37}$ [Roseville B[2]]. Its heat of formation is approximately –595 cal/g, and a typical density is about 0.0542 lb/in$^3$ ($1.50\times10^3$ kg/m$^3$). The chemical formula for phenolphthalein is $C_{20}H_{14}O_4$. Its heat of formation is approximately –431 cal/g, and its density is 0.0461 lb/in$^3$ ($1.28\times10^3$ kg/m$^3$).

Ingredients can be placed in the **INPUT.DAT** file as user defined ingredients; however, if they are added to **PEPCODED.DAF**, they will be available for future use. Use an **ASCII** editor to add charcoal and phenolphthalein to the end of **PEPCODED.DAF** as lines 1093 and 1094. Each item on a line must be aligned with the item above it. All numeric fields are right justified and all letter fields are left justified. Use only capital letters in **PEPCODED ENTRIES**. Be sure to place the "**]**" at the end of each line.

For the first part of the demonstration, edit the **INPUT.DAT** file to run black powder made with charcoal. This example uses 74% potassium nitrate, 10.4% sulfur, and 15.6% charcoal (a standard black powder composition.[5] The first line in **INPUT.DAT** is the name of the output file. Type:

"BLKPWDRC.OUT"

Line 1 has only one field with a length of up to 12 characters. This allows the use of a standard filename structure (up to an eight character filename, a period ".", and a three character extension). The second line describes the file and will be printed at the top of each output page. For the second line type: "Charcoal BP". The second line contains one field that can be up to 17 characters long. Three items are entered on Line 3: the number of the **PEPCODED.DAF** ingredients used, the number of user defined ingredients (zero if all ingredients are in the ingredient file – **PEPCODED.DAF**), and the number of cases to be run (one case for each chamber pressure and/or formulation). In this example, results will be calculated for two chamber pressures, 29.4 and 1000 psia (203 kPa and 6.89 MPa). Each field in Line 3 is five characters long, thus for Line 3 type:

"~~bbbb~~3~~bbbb~~0~~bbbb~~2"

(where, ~~b~~ is used to indicate a blank space). Remember, spacing is critical. Line 4 is used for calculating density $I_{SP}$ and is also used with control option 3 in Line 7. From the **MICROPEP** instructions, *"For the evaluation of non-rocket chemical equilibrium of any type, propellant screening, tactical missiles, first stage rockets a value of 1 should be input. If performance of upper stages is the topic of analysis, appropriate values are 0.7 for second stage, and 0.2 for third stage. This requires use of control option three."* Control options are set in Line 7. For Line 4 type: "1." Line 4 contains a single field with a length of up to 12 characters. Line 5 is the initial temperature of the ingredients, in Kelvin, and can be used to study temperature conditioning effects. Type: "298." [This is 25 °C (77 °F).] Line 5 has one field that may be 12 characters long. Line 6 contains the *"Quadratic coefficients for solid specific heat. Used with temperature difference to adjust the system enthalpy for heating and cooling. (defaults to 0.3 cal/gm K)."* The previous quote is from **PROPEP.TXT**. Line 6 has three fields, each 12 characters long. For Line 6 type:

".3~~bbbbbbbbbb~~0.0~~bbbbbbbbbb~~0.0"

Line 7 has eight fields, each one character long. These fields function as switches to select control options. "0" is used for off and "1" for on. The options are (again, quoting from the **PROPEP.TXT** file):

1) *Delete exit calculations*
2) *Include ionic species in calculations*
3) *Include boost velocities and nozzle design data*
4) *Input pressures in atmospheres instead of PSI*
5) *Increase numerical precision of species list*
6) *Output a list of all combustion species considered*
7) *Fix temperature*
8) *Debug options*

For Line 7 type: "00000000". Line 8 holds the line numbers for the ingredients from the **PEPCODED.DAF** file. For Line 8 type:

"~~bb~~821~~bb~~898~~b~~1093".

These are the line numbers for potassium nitrate, sulfur, and charcoal, respectively. Line 8 contains up to 10 fields, each five characters long. Line 9 (repeated once for each case to be run) contains selected chamber pressure, selected exhaust pressure, and the weight percentage of each ingredient. Use the same order of ingredients as in Line 8. Weights may be used instead of percentages, if preferred. Each repetition of Line 9 can have up to 12 fields, each with 12 characters. For Lines 9 and 10 type:

~~bbbbbbbb~~29.4~~bbbbbb~~14.70~~bbbbbbb~~74.00~~bbbb bbb~~10.40~~bbbbbbb~~15.60
~~bbbbbb~~1000.0~~bbbbbbb~~14.70~~bbbbbbb~~74.00~~bbb bbbb~~10.40~~bbbbbbb~~15.60

After editing, the file should look like:

```
BLKPWDRC.OUT
Charcoal BP
    3    0    2
1.
298.
.3          0.0         0.0
00000000
  821  898 1093
  29.4       14.70       74.00       10.40       15.60
1000.0       14.70       74.00       10.40       15.60
```

All of **PROPEP**'s functions are not being used, thus the above line numbers are not the same as those given in **PROPEP.TXT**. Lines 8 and 10 were not used, so Line 8 corresponds with **PROPEP.TXT**'s Line 9 and Line 9 corresponds with Line 11. Note that for the first case, a chamber

pressure of 29.4 psia (203 kPa) is used. **PROPEP** does not operate reliably with pressures lower than this, although it sometimes provides results. The second case will be run at 1000 psia (6.89 MPa), which is a standard pressure for comparison of propellants. (Note that more information about the input file configuration and use is available in the **PROPEP.TXT** file.) Save the new **INPUT.DAT** file and exit the editor; then type "**PROPEP**" and press the Enter key to run the charcoal evaluations. When the program run is finished, print the results, which are contained in the file

**BLKPWDRC.OUT**.

To continue this demonstration, again edit **INPUT.DAT** and change Line 1 to:

"BLCKPWDRP.OUT".

Change Line 2 to "Phenolphthalein BP" In Line 8, change "1093" to "1094". Save the file **INPUT.DAT** and exit the editor. Type "**PROPEP**" and press the Enter key to run. When the program is finished, print the **BLKPWDRP.OUT** file. Sample printouts for the higher pressure runs follow as Figures 1 and 2.

Based on these calculated results, phenolphthalein looks like a good substitute for charcoal in black powder. The sample cases have similar chamber temperatures, specific heat ratios, characteristic exhaust velocities, densities, etc. In fact, phenolphthalein might be better than charcoal if the black powder is to be used as a rocket propellant. However, this is only part of the story. Real life testing must also be performed to prove that the substitute black powder will work in the desired application. If the results had varied widely, we probably wouldn't want to actually try using phenolphthalein in a black powder substitute. Thus **PROPEP** can be used as a tool to help minimize experimentation with "real" mixes. It can help optimize a formulation in a much shorter time.

Thus far, phenolphthalein has been determined to be a good candidate to replace charcoal in a black powder substitute. The next step could be to vary the composition to help decide whether or not to use the standard black powder percentages. To do this, edit the **INPUT.DAT** file again. This time, change Line 1 to "PHENOLBP.OUT". Notice the use of output file names that indicate something about their content. Change the last field in Line 3 from "2" to "3". The percentage of potassium nitrate will be held constant and the percentages of sulfur and phenolphthalein will be varied. To do this, make changes as shown below:

```
PHENOLBP.OUT
Phenolphthalein BP
    3    0    3
1.
298.
.3          0            0
00000000
  821  898 1094
1000.00     14.70       74.00       10.40       15.60
1000.00     14.70       74.00       13.00       13.00
1000.00     14.70       74.00       15.60       10.40
```

Save **INPUT.DAT** and run **PROPEP** again. After the run, print the file, **PHENOLBP.OUT**. Examine the values for C* (characteristic exhaust velocity — a good indication of propellant efficiency). Note that either change lowered C* below its original (or Case 1) value. Accordingly, if the substitute black powder is to be used in a rocket motor, the "standard" composition appears best. However, it may still be advantageous to try other chemical ratios. In addition, the experimenter may wish to raise or lower the chamber temperature for some applications. Formulations may be altered to increase or decrease the amounts of a given reaction product to enhance a desired effect; and densities may be adjusted by varying the composition. **PROPEP** can be used to quickly help determine the "best" tradeoff.

This gives some idea of **PROPEP**'s capabilities. As mentioned earlier, **PROPEP** does not provide burn rate information. If burn rate information is available from another source or from testing, it can be combined with **PROPEP**'s output information for preliminary rocket motor design.

Some key relationships used in rocket motor design[6,7] are:

$$r = a \cdot P_c^n$$

$$Kn = b \cdot P_c^{1-n}$$

$$P_c = c \cdot Kn^{(1/1-n)}$$

$$Kn = (P_c \cdot g) / (r \cdot \rho \cdot C^*)$$

In these equations:

- r is burn rate (in/s in the English system),
- a is the burn rate coefficient,
- $P_c$ is chamber pressure (psia), and
- n is the burn rate exponent. (It is also the slope of a log-log plot of burn rate and chamber pressure.)
- Kn is burning surface area divided by nozzle throat area (both in same units).
- b is the Kn coefficient
- c is the pressure coefficient,
- g is gravitational constant (32.17 ft/sec$^2$ ),
- ρ is propellant density (lb/in$^3$), and
- C* is characteristic exhaust velocity (ft/sec).

For conversion to SI Units:

| | | |
|---|---|---|
| 1 in/sec | = | 25.4 mm/s |
| 1 psi | = | 6.89 kPa |
| 1 lb/in$^3$ | = | 2.77x10$^4$ kg/m$^3$ |
| 1 ft/s$^2$ | = | 0.305 m/s$^2$ |
| 1 ft/s | = | 0.305 m/s |

```
Charcoal BP       Run using June 1988 Version of PEP,
 Case  2 of  2      7 Apr 1995 at  6:41:33.94 pm

  CODE                                  WEIGHT    D-H  DENS      COMPOSITION
   821 POTASSIUM NITRATE                74.000  -1167  0.07670    1N   3O   1K
   898 SULFUR                           10.400      0  0.07470    1S
  1093 Charcoal                         15.600   -595  0.05420  322C 184H  37O   1N
THE PROPELLANT DENSITY IS 0.07185 LB/CU-IN OR  1.9887 GM/CC
THE TOTAL PROPELLANT WEIGHT IS  100.0000 GRAMS
NUMBER OF GRAM ATOMS OF EACH ELEMENT PRESENT IN INGREDIENTS
   0.616095 H     1.078166 C     0.735239 N     2.319561 O
   0.324331 S     0.731891 K
***************************CHAMBER RESULTS FOLLOW    ****************************
 T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY   CP/CV     GAS   RT/V
1917. 2991.   68.02  1000.00   -95.64   134.63  1.1118  1.631   41.702
SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL=   11.324   16.325
NUMBER MOLS GAS AND CONDENSED=   1.6312   0.3440
  0.51358 CO2        0.36759 N2         0.34650 CO         0.23798 H2O
  0.21417 K2CO3*     0.12978 K2S*       0.05251 S3         0.04008 KHO
  0.03774 H2         0.01174 H2S        0.00984 SO2        0.00405 S2
 3.84E-03 CSO       3.34E-03 K         7.37E-04 HS        7.02E-04 SO
 3.69E-04 S4        1.91E-04 S2O       1.42E-04 K2SO4     1.17E-04 K2H2O2
 2.72E-05 H         1.79E-05 S         1.58E-05 KH        1.49E-05 HO
 6.78E-06 CS2       4.40E-06 NH3       4.14E-06 KCN       1.64E-06 K2
 1.40E-06 NO
THE MOLECULAR WEIGHT OF THE MIXTURE IS   50.628
***************************EXHAUST RESULTS FOLLOW    ****************************
 T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY   CP/CV     GAS   RT/V
1289. 1861.    1.00    14.70  -117.40   134.63  1.1178  1.633    0.612
SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL=   10.959   15.419
NUMBER MOLS GAS AND CONDENSED=   1.6332   0.3642
  0.67260 CO2        0.36759 N2         0.24617 H2O        0.24480 CO
  0.20465 K2S*       0.15950 K2CO3*     0.05219 H2         0.03650 S3
 8.01E-03 H2S       3.25E-03 KHO       1.21E-03 CSO       3.02E-04 K
 2.63E-04 S2        1.64E-04 SO2       4.57E-05 S4        2.30E-05 HS
 3.98E-06 K2H2O2    3.25E-06 SO        2.49E-06 K2SO4     1.25E-06 S2O
THE MOLECULAR WEIGHT OF THE MIXTURE IS   50.066
**********PERFORMANCE:  FROZEN ON FIRST LINE, SHIFTING ON SECOND LINE**********
IMPULSE   IS EX      T*      P*      C*    ISP*  OPT-EX  D-ISP      A*M   EX-T
  136.2  1.1138   1814.   39.58  2648.6           10.66  270.9  0.08234  1245.
  137.6  1.0977   1825.   39.80  2672.8   101.6   10.83  273.7  0.08309  1289.
```

*Figure 1. Sample output from standard black powder run at 1000 psia (6.89 MPa).*

```
Phenolpthalein BP Run using June 1988 Version of PEP,
 Case  2 of  2     27 Mar 1995 at  7:13: 1.67 pm

  CODE                                  WEIGHT    D-H  DENS      COMPOSITION
   821 POTASSIUM NITRATE                74.000  -1167  0.07670    1N   3O   1K
   898 SULFUR                           10.400      0  0.07470    1S
  1094 Phenolpthalein                   15.600   -431  0.04610   20C  14H   4O

THE PROPELLANT DENSITY IS 0.06933 LB/CU-IN OR  1.9190 GM/CC
THE TOTAL PROPELLANT WEIGHT IS  100.0000 GRAMS

NUMBER OF GRAM ATOMS OF EACH ELEMENT PRESENT IN INGREDIENTS
   0.686076 H     0.980109 C     0.731891 N     2.391694 O
   0.324331 S     0.731891 K

****************************CHAMBER RESULTS FOLLOW    ****************************
 T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY   CP/CV     GAS   RT/V
2052. 3235.   68.02  1000.00   -93.08   137.96  1.1190  1.685   40.367

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL=   11.464   15.768
NUMBER MOLS GAS AND CONDENSED=   1.6852   0.3115
  0.50939 CO2         0.36591 N2          0.34364 CO          0.24997 H2O
  0.12417 K2CO3*      0.12393 K2S*        0.09710 KHO         0.06333 K2SO4*
  0.03553 H2          0.02925 S3          0.02410 SO2         0.01004 K
 8.04E-03 H2S        4.69E-03 S2         2.84E-03 CSO        1.90E-03 SO
 1.04E-03 HS         5.86E-04 K2SO4      3.24E-04 S2O        3.03E-04 K2H2O2
 1.73E-04 S4         6.84E-05 H          5.39E-05 HO         5.26E-05 KH
 4.82E-05 S          1.09E-05 K2         6.53E-06 NO         5.82E-06 KCN
 4.54E-06 KO         3.72E-06 CS2        3.09E-06 NH3        1.71E-06 NS

THE MOLECULAR WEIGHT OF THE MIXTURE IS   50.085
****************************EXHAUST RESULTS FOLLOW    ****************************
 T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY   CP/CV     GAS   RT/V
1417. 2092.    1.00    14.70  -117.16   137.96  1.1217  1.654    0.605

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL=   11.188   15.099
NUMBER MOLS GAS AND CONDENSED=   1.6536   0.3526
  0.68984 CO2         0.36592 N2          0.28567 H2O         0.22898 CO
  0.21977 K2S*        0.07216 K2SO4*      0.06066 K2CO3*      0.04237 H2
  0.02337 KHO         0.00887 S3          0.00323 H2S         0.00307 K
 1.15E-03 SO2        5.72E-04 CSO        3.02E-04 S2         7.56E-05 K2SO4
 4.15E-05 HS         4.00E-05 K2H2O2     2.48E-05 SO         7.24E-06 S4
 3.55E-06 S2O        1.63E-06 H

THE MOLECULAR WEIGHT OF THE MIXTURE IS   49.845
**********PERFORMANCE:  FROZEN ON FIRST LINE, SHIFTING ON SECOND LINE**********

IMPULSE   IS EX      T*       P*      C*    ISP*  OPT-EX  D-ISP      A*M   EX-T
  142.5  1.1213   1935.   39.47  2778.4           10.48  273.4  0.08638  1300.
  144.8  1.0982   1954.   39.80  2811.0   106.9   10.90  277.8  0.08739  1417.
```

*Figure 2. Sample output from phenolphthalein black powder run at 1000 psia (6.89 MPa).*

The **PROPEP.TXT** file provides more information on interpretation of **PROPEP**'s output. Warning: in the output file, specific impulse ($I_{SP}$) is labeled as "**IMPULSE"** below the "**PERFORMANCE: FROZEN ON FIRST LINE, SHIFTING ON SECOND LINE**". If instructions refer to $I_{SP}$ with no *'s or other modifiers, they mean the **IMPULSE** value. Sutton[1] is an excellent source of information on rocket propulsion topics. The sixth edition has improved and expanded coverage.

## References


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