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Iron/Potassium Perchlorate Pellet Burn Rate Measurements

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Abstract

A burn rate test having several advantages for low gas-producing pyrotechnic compacts has been developed. The technique involves use of a high speed video motion analysis system that allows immediate turnaround and produces all required data for rate computation on magnetic tape and becomes immediately available on the display screen. The test technique provides a quick method for material qualification along with data for improved reliability and function.

Burn rate data has been obtained for both UPI and Eagle - Pitcher Iron / Potassium Perchlorate blends. The data obtained for the UPI blends cover a range of composition, pellet density, and ambient (before ignition) pellet temperature. Burn rate data for the E-P blends were extended to include surface conditions or particle size as a variable parameter.

Introduction

Burn rate tests are often used as material qualification tests and as means of predicting performance of pyrotechnic blends. For example, in development of propellant or heat source blends, the rate of energy production is extremely dependent on burn rate, among other parameters. The driving interest in this work was to improve the function and performance of the Iron/Potassium Perchlorate pyrotechnic blend used as a heat source to drive thermal batteries.

The objective of the work described here is to develop a rapid method for measuring the burn rate of gasless pyrotechnic heat sources and to then

measure and relate burn rate data to various parameters known and suspected to contribute to burn rate variations in the system iron/potassium perchlorate. Several parameters are deliberately varied in device applications to tailor the burn rate to satisfy device requirements. These parameters have usually been the relative composition of the blend components and the density of the compact. Variations in physical properties of the materials composing the blend also contribute to variation in burn rate of the blend compacts.

Experimental

The burn rate apparatus consists of a controlled temperature surface on which the pyrotechnic sample pellet rests. Various substrate materials may be inserted between that surface and the sample pellet. In this manner, the physical properties of the substrate material can be varied, and the effects of this variation on the burn rate may be observed.

The temperature of the surface can be varied from less than -54°C to temperatures in excess of 150°C . It has been found that the temperature of the sample pellet varies less than 3°C from the measured temperature of the underlying surface during an observation. Because the control temperature is not usually very far from ambient in this work, a fair amount of temperature oscillation can be observed.

Ignition is initiated when the temperature of the pellet reaches the required temperature. An optical quartz cover is used to prevent separation of the pellet from the substrate during burning and to provide a consistent surface contact with the upper face of the pellet. The cover is three inches in diameter and one quarter inch thick, covering two or three pellets. Initiation is by electric match. The intent is to measure duplicate or triplicate samples by propagation of the burn from one pellet to another across an edge.

A high speed video motion analysis system is used to observe the motion of the burn front across the surface of the pellet and to measure the time and distance associated with this process. The high temperature reaction front can be easily followed and recorded on video tape. The record rate can be varied from standard VHS rates to 12,000 events per second. For this work,

recording at 1000 frames per second has been sufficient to capture these events. Each frame recorded and stored on tape contains the position of the reaction front and an associated elapsed time from an arbitrary time base. The motion analysis system also provides a means of measurement of the position of the burn front using video screen reticles. This allows the measurement of distance intervals across a convenient number of frames sufficient to calculate reliable burn rate values. The high speed video tape provides a permanent record of the events.

Results

The first set of burn rate measurements was done with the object of determining the effect on burn rate of the substrate in contact with the Fe/KClO_4 (88/12) pellet. All burn rate determinations were made on 1.5-inch diameter pellets. The substrate material was chosen so that a wide range of specific heat and thermal conductivity would be represented. The materials were copper, aluminum, graphite, quartz, and an insulating material, MinK. Quartz was included to determine its effect as a covering material, which was used throughout the complete series of measurements after it was discovered that a cover was required to obtain reproducible results. This was probably the effect of the reduction of nonreproducible heat loss caused by the hot, volatile potassium chloride that was produced in the pyrotechnic reaction. With the quartz cover plate in place, the sample pellet did not move or deform as it did with no cover, thus allowing much of the potassium chloride to remain condensed between the pellet and the substrate and cover.

The effect of the substrate material on the burn rate of Fe/KClO_4 pellets is small, as can be seen in Figure 1, where the variation in rate between substrates is shown to be about the same as the spread observed for each individual substrate.

Pellet thickness has no effect on burn rate over the thickness range observed, as can be seen from the data of Figure 2, where the results of

Figure 1 - Burn rates of Fe/K (88/12), density 3.35 show small variation with adjacent substrate.

Figure 2 - Burn rate of Fe/K (88/12) pellets shows no variation with thickness.

determinations on pellets at three temperatures and three thicknesses are shown. The rather pronounced effect of temperature on burn rate is, however, shown very nicely here. At some small value of thickness it would be expected that the effect of thermal conductivity would be great enough to remove heat from the bulk of the pellet and decrease the propagation rate, but the effect cannot yet be seen within this thickness range. Of the variables investigated in this series of determinations (temperature, substrate properties, and pellet thickness) only temperature was observed to have had a significant effect.

A second set of burn rate measurements was done on samples of Fe/KClO_4 blended at UPI for comparison purposes and to determine what effect the fuel-to-oxidizer ratio (Fe/KClO_4), pellet density, and pre-ignition pellet temperature had on the burn rate. The burn rate measurements were done over a range of densities from 3.0 to 4.0 g/mL. The composition range covered Fe/KClO_4 ratios 84/16, 86/14, and 88/12, and the temperatures covered were -54°C and 74°C .

Figures 3 through 9 show the burn rate data obtained from this series of determinations. The combination of parameters chosen for each plot was chosen to show the variation in burn rate with the variables in an easily understandable set. Each figure contains several related sets of raw data shown as points and three constant polynomial least square fits for each set, shown as line plots.

Figures 3, 4 and 5 show the variation of the burn rate with the independent variable composition (Fe/KClO_4) at two values of temperature. Least square fits of burn rate over composition are shown for each temperature. Figures 3, 4, and 5 contain the data obtained for pellet densities 3.0, 3.5 and 4.0 g/cc respectively. Figures 6 and 7 show the variation of burn rate with composition at several values of density along with the line plots showing the least square fits of burn rate over composition for each density value. Figures 6 and 7 contain the data obtained for temperatures -54°C and 74°C respectively. Again, as in Figures 3 through 7, the burn rate data are shown as plots against density for the several values of composition. Again the least square fits are shown as line plots. Figures 8 and 9 contain the data obtained for temperatures -54°C and 74°C respectively. It should be

Figure 3 - Burn rate of FeK (UPI) as a function of composition (density = 3.0 g/mL).

Figure 4 - Burn rate of FeK (UPI) as a function of composition for $T = 74$ and -54°C (density = 3.5 g/mL).

Figure 5 - Burn rate of FeK (UPI) as a function of composition (density = 4.0 g/mL).

Figure 6 - Burn rate of FeK (UPI) as a function of composition (temperature = -54°C).

Figure 7 - Burn rate of FeK (UPI) as a function of composition (temperature = 74°C).

Figure 8 - Burn rate of FeK (UPI) as a function of density (temperature = -54°C).

Figure 9 - Burn rate of FeK (UPI) as a function of density (temperature = 74°C).

understood that while there are redundant plots of the data, each line plot throughout this series is represented by separate sets of polynomial constants.

To obtain a useful representation of the burn rate data for the UPI blends, all the data was fitted to a seven parameter equation, second order in density, composition, and temperature. The form of the equation for burn rate, R , is

$$R = A(1) + A(2)(\%Fe) + A(3)(\%Fe)^2 + A(4)(g/mL) + A(5)(g/mL)^2 + A(6)(T) + A(7)(T)^2$$

and the parametric constants for the fit are

$$\begin{aligned} A(1) &= -57285.7758 \\ A(2) &= 178.273214 \\ A(3) &= -26.3931066 \\ A(4) &= 0.168684709 \\ A(5) &= 0.00436132428 \\ A(6) &= 1316.53344 \\ A(7) &= -7.58815575 \end{aligned}$$

The standard deviation for the fit is 7.1 mm/s.

The complete UPI burn rate data are contained in Table 1 along with the computed burn rates and the associated deviations. Figures 10 through 16 show the UPI data along with a representation of the fit obtained over all of the parameters for that burn rate data. The data are shown in the same order as in the previous figures, and the raw burn rate data duplicate the previous figures. The line plots, however, represent the above seven parameters fit over the complete set of UPI burn rate data, rather than individual fits for each data set. In general, the plots of the fitting equation represent the data reasonably well over the complete range of data. The line plots representing burn rate as a function of density for -54° C in Figure 15 show the largest deviation and a further inspection of the plotted data may be desirable when using the fitting equation for burn rate estimation in this region. Somewhat tighter fits can be obtained by extending and

**Table 1 - BURN RATE OF FeK (UPD) AS A FUNCTION OF DENSITY,
TEMPERATURE AND COMPOSITION**

POLYNOMIAL COEFFICIENTS

B(1)=-5.72857758E+04
 B(2)= 1.78273214E+02
 B(3)=-2.63931066E+01
 B(4)= 1.68684709E-01
 B(5)= 4.36132428E-03
 B(6)= 1.31653344E+03
 B(7)=-7.58815575E+00

#	DENSITY g/ml	TEMPERATURE C	% IRON	BURN RATE mm/s	CALC	DELTA
1	3.50000000E+00	7.40000000E+01	8.80000000E+01	1.39200000E+02	1.43494472E+02	-4.29447234E+00
2	3.50000000E+00	7.40000000E+01	8.80000000E+01	1.50600000E+02	1.43494472E+02	7.10552766E+00
3	4.00000000E+00	7.40000000E+01	8.80000000E+01	1.44000000E+02	1.33656930E+02	1.03430702E+01
4	4.00000000E+00	7.40000000E+01	8.80000000E+01	1.45200000E+02	1.33656930E+02	1.15430702E+01
5	3.50000000E+00	7.40000000E+01	8.80000000E+01	1.43400000E+02	1.43494472E+02	-9.44723358E-02
6	3.50000000E+00	7.40000000E+01	8.80000000E+01	1.48500000E+02	1.43494472E+02	5.00552766E+00
7	3.00000000E+00	7.40000000E+01	8.80000000E+01	1.35800000E+02	1.40135462E+02	-4.33546162E+00
8	3.00000000E+00	7.40000000E+01	8.80000000E+01	1.41900000E+02	1.40135462E+02	1.76453838E+00
9	4.00000000E+00	7.40000000E+01	8.80000000E+01	1.44400000E+02	1.33656930E+02	1.07430702E+01
10	4.00000000E+00	7.40000000E+01	8.80000000E+01	1.45100000E+02	1.33656930E+02	1.14430702E+01
11	4.00000000E+00	9.00000000E+01	8.80000000E+01	1.40000000E+02	1.47800000E+02	-7.80000000E+00
12	4.00000000E+00	9.00000000E+01	8.80000000E+01	1.55600000E+02	1.47800000E+02	7.80000000E+00
13	4.00000000E+00	7.40000000E+01	8.80000000E+01	1.30300000E+02	1.33656930E+02	-3.35692976E+00
14	4.00000000E+00	7.40000000E+01	8.80000000E+01	1.38300000E+02	1.33656930E+02	4.64307024E+00
15	3.50000000E+00	7.40000000E+01	8.60000000E+01	1.50000000E+02	1.51105799E+02	-1.10579942E+00
16	3.50000000E+00	7.40000000E+01	8.60000000E+01	1.53200000E+02	1.51105799E+02	2.09420058E+00
17	4.00000000E+00	7.40000000E+01	8.60000000E+01	1.34900000E+02	1.41268257E+02	-6.36825684E+00
18	4.00000000E+00	7.40000000E+01	8.60000000E+01	1.43200000E+02	1.41268257E+02	1.93174316E+00
19	3.00000000E+00	7.40000000E+01	8.60000000E+01	1.47000000E+02	1.47746789E+02	-7.46788699E-01
20	3.00000000E+00	7.40000000E+01	8.60000000E+01	1.52600000E+02	1.47746789E+02	4.85321130E+00
21	3.50000000E+00	7.40000000E+01	8.60000000E+01	1.60200000E+02	1.51105799E+02	9.09420058E+00
22	3.50000000E+00	7.40000000E+01	8.60000000E+01	1.47400000E+02	1.51105799E+02	-3.70579942E+00
23	3.50000000E+00	7.40000000E+01	8.60000000E+01	1.54700000E+02	1.51105799E+02	3.59420058E+00
24	3.00000000E+00	7.40000000E+01	8.60000000E+01	1.39000000E+02	1.47746789E+02	-8.74678870E+00
25	3.00000000E+00	7.40000000E+01	8.60000000E+01	1.45000000E+02	1.47746789E+02	-2.74678870E+00
26	4.00000000E+00	7.40000000E+01	8.60000000E+01	1.38400000E+02	1.41268257E+02	-2.86825684E+00
27	4.00000000E+00	7.40000000E+01	8.60000000E+01	1.42300000E+02	1.41268257E+02	1.03174316E+00
28	4.00000000E+00	7.40000000E+01	8.60000000E+01	1.36400000E+02	1.41268257E+02	-4.86825684E+00

**Table 1 - BURN RATE OF FeK (UPI) AS A FUNCTION OF DENSITY,
TEMPERATURE AND COMPOSITION (continued)**

29	4.00000000E+00	7.40000000E+01	8.60000000E+01	1.41700000E+02	1.41268257E+02	4.31743162E-01
30	3.00000000E+00	7.40000000E+01	8.40000000E+01	9.35000000E+01	9.46528698E+01	-1.15286978E+00
31	3.00000000E+00	7.40000000E+01	8.40000000E+01	8.54000000E+01	9.46528698E+01	-9.25286978E+00
32	3.00000000E+00	7.40000000E+01	8.40000000E+01	9.50000000E+01	9.46528698E+01	3.47130218E-01
33	3.00000000E+00	7.40000000E+01	8.40000000E+01	9.80000000E+01	9.46528698E+01	3.34713022E+00
34	3.50000000E+00	7.40000000E+01	8.40000000E+01	8.54000000E+01	9.80118805E+01	-1.26118805E+01
35	3.50000000E+00	7.40000000E+01	8.40000000E+01	8.77000000E+01	9.80118805E+01	-1.03118805E+01
36	4.00000000E+00	7.40000000E+01	8.40000000E+01	7.87000000E+01	8.81743379E+01	-9.47433792E+00
37	4.00000000E+00	7.40000000E+01	8.40000000E+01	8.49000000E+01	8.81743379E+01	-3.27433792E+00
38	3.50000000E+00	-5.40000000E+01	8.80000000E+01	1.16000000E+02	1.10737839E+02	5.26216056E+00
39	4.00000000E+00	-5.40000000E+01	8.80000000E+01	8.22000000E+01	1.00900297E+02	-1.87002969E+01
40	3.00000000E+00	-5.40000000E+01	8.80000000E+01	9.83000000E+01	1.07378829E+02	-9.07882872E+00
41	3.00000000E+00	-5.40000000E+01	8.80000000E+01	9.93000000E+01	1.07378829E+02	-8.07882872E+00
42	4.00000000E+00	-5.40000000E+01	8.80000000E+01	1.00800000E+02	1.00900297E+02	-1.00296863E-01
43	3.50000000E+00	-5.40000000E+01	8.80000000E+01	1.05000000E+02	1.10737839E+02	-5.73783944E+00
44	3.50000000E+00	-5.40000000E+01	8.80000000E+01	1.04200000E+02	1.10737839E+02	-6.53783944E+00
45	3.50000000E+00	-5.40000000E+01	8.80000000E+01	1.03200000E+02	1.10737839E+02	-7.53783944E+00
46	3.00000000E+00	-5.40000000E+01	8.60000000E+01	1.17200000E+02	1.14990156E+02	2.20984419E+00
47	3.00000000E+00	-5.40000000E+01	8.60000000E+01	1.17400000E+02	1.14990156E+02	2.40984419E+00
48	3.50000000E+00	-5.40000000E+01	8.60000000E+01	1.21700000E+02	1.18349167E+02	3.35083347E+00
49	3.50000000E+00	-5.40000000E+01	8.60000000E+01	1.21700000E+02	1.18349167E+02	3.35083347E+00
50	3.50000000E+00	-5.40000000E+01	8.60000000E+01	1.20900000E+02	1.18349167E+02	2.55083347E+00
51	4.00000000E+00	-5.40000000E+01	8.60000000E+01	1.08100000E+02	1.08511624E+02	-4.11623945E-01
52	4.00000000E+00	-5.40000000E+01	8.60000000E+01	1.07000000E+02	1.08511624E+02	-1.51162395E+00
53	4.00000000E+00	-5.40000000E+01	8.60000000E+01	1.03400000E+02	1.08511624E+02	-5.11162395E+00
54	4.00000000E+00	-5.40000000E+01	8.60000000E+01	1.09800000E+02	1.08511624E+02	1.28837605E+00
55	3.00000000E+00	-5.40000000E+01	8.40000000E+01	7.67000000E+01	6.18962369E+01	1.48037631E+01
56	3.00000000E+00	-5.40000000E+01	8.40000000E+01	7.63000000E+01	6.18962369E+01	1.44037631E+01
57	4.00000000E+00	-5.40000000E+01	8.40000000E+01	5.46000000E+01	5.54177050E+01	-8.17705029E-01
58	3.50000000E+00	-5.40000000E+01	8.40000000E+01	7.03700000E+01	6.52552476E+01	5.11475239E+00
59	3.50000000E+00	-5.40000000E+01	8.40000000E+01	7.06700000E+01	6.52552476E+01	5.41475239E+00
60	4.00000000E+00	-5.40000000E+01	8.40000000E+01	5.54000000E+01	5.54177050E+01	-1.77050288E-02
61	4.00000000E+00	-5.40000000E+01	8.40000000E+01	5.89000000E+01	5.54177050E+01	3.48229497E+00

SIGMA = 7.12858163315

Figure 10 - Burn rate of FeK (UPI) as a function of composition (density = 3.0 g/mL, 7 PAR.FIT).

Figure 11 - Burn rate of FeK (UPI) as a function of composition (density = 3.5 g/mL, 7 PAR.FIT).

Figure 12 - Burn rate of FeK (UPI) as a function of composition (density = 4.0 g/mL, 7 PAR.FIT).

Figure 13 - Burn rate of FeK (UPI) as a function of composition (temperature = -54°C).

Figure 14 - Burn rate of FeK (UPI) as a function of composition (temperature = 74°C).

Figure 15 - Burn rate of FeK (UPI) as a function of density (temperature = -54°C).

Figure 16 - Burn rate of FeK (UPI) as a function of density (temperature = 74°C).

complicating the form of the fitting equation, but the convoluted plots obtained hardly justify the small improvements in fit.

A third set of burn rate determinations were measured on pellets prepared from several Iron / Potassium Perchlorate blends obtained from Eagle - Pitcher Corporation. These blends were chosen to determine the effect of iron particle size (surface area) on burn rate, in addition to the effect of the parameters previously discussed. Most of the measurements covered the density range from 3 to 4 g/mL, while a select group of measurements covered the extended range 2.5 to 5 g/mL. The pellet pre-ignition temperature range covered was -54° C to 140° C, a larger range than that for previous cases. The composition range covered was, as in the previous cases, 84 to 88% iron. Both Fe/KClO₄ composition and particle size of the iron powder in the E-P blends were used to control the powder burn rates of these blends. The particle size data for the iron powder in these blends were obtained as a particle size distribution.

The data were presented as percent iron particles greater than given values versus particle size, as shown graphically in Figure 17. This presentation does not easily lend itself to correlations with burn rate data, since a single value variable is not directly available. Either the average particle size or the integrated surface area may be calculated for the purpose of correlation. Computation of surface area was chosen for the correlation.

The surface area value used for correlation purposes was obtained by assuming a spherical particle geometry, computing the spherical surface areas, and integrating over all particles. The surface area values obtained were thus relative values relating the surface areas of the various iron component materials in the blends. No measured values for the surface areas of the iron materials were available. These calculated surface areas, referred to as surface functions, are shown in Table 2 along with the average particle size, the blend ratio (Fe/KClO₄), the nominal open train powder burn rate, and the Sandia National Laboratory blend number.

The variation of burn rate with density for the above blends at several temperatures (-54°, 25°, 74°, and 140° C) is shown in Figures 18 through 25. Each figure represents individual values of Fe/KClO₄ ratios and surface

Table 2 - SURFACE FUNCTIONS				
BLEND # PBF-	Fe/KClO ₄ RATIO	SURFACE FUNCTION	Fe AVG. MICRONS	NOMINAL RATE
0395	88/12	23.7	10.5	4.56
0396	86/14	23.7	10.5	2.71
0400	86/14	14.9	18.6	3.9
0401	84/16	13.7	20.3	4.28
0402	84/16	24.07	10.5	5.1
0404	84/16	9.8	37.3	3.02
0405	86/14	11.0	31.3	2.55
0406	88/12	28.0	8.8	5.87

functions. The points represent individual measurements of burn rates. The line plots are obtained from individual, three-parameter, polynomial least square fits of burn rate as a function of density for each set of remaining independent variables. Figures 18 and 19 are somewhat misleading on first inspection because not enough variation in density values are shown to indicate the curvature and the maxima, which can be observed in the figures following (20-25).

In several figures (23, 24) the density varies over the range 2.5 to 5.0 g/mL. These figures represent the only sets of data over this wide range of density values primarily because of the difficulty in pressing pellets at the extreme low and high ends of the range. At the low end of the range (2.5 g/mL) handling of the pellets which were available was very difficult without breaking the pellets. Pellets in the 4.5 to 5.0 g/mL density range were extremely difficult to ignite. In general the maximum values in burn rate appear at densities of approximately 3.2 to 3.4 g/mL. In these figures the burn rate varies directly with temperature over the full temperature range of the measurements. These figures cover the full range of all of the variables studied. The rather consistent variation of burn rate with density and

temperature in Figures 18 through 25 suggests the possibility of fitting burn rate to some linear combination of density and temperature over the range of measurements.

The general trend in burn rate with surface function is shown in Figures 26 through 32 for the several values of Fe/KClO₄ ratio. The trend in burn rate with surface function for the 88/12 Fe/KClO₄ blend is different than that for the other two blends (86/14 and 84/16). This trend is consistent over the density and temperature ranges for this blend. The range of surface function values available for this blend is not, however, the same as that for the other two blends (86/14 and 84/16). The high surface function blends for 86/14 and 84/16 ratios and the low surface function blends for the 88/12 ratio are missing.

It appears that the high ratio blend behaves differently than the lower ratio blends. Without burn rate data for the extended values this discrepancy cannot be resolved. The inverse plots are shown in Figures 33 through 36 where burn rate is plotted as a function of blend ratios at several values of surface function, temperature and density. In Figures 33 and 35 the density is 3.5 g/mL and in 34 and 36 it is 4.0 g/mL. No set of pellets covering a wide enough range of Fe/KClO₄ compositions made from iron of a single surface area was available to produce any of these curves. Each curve is made up of burn rate data from blends of similar surface area iron. The burn rates obtained for the high values of surface function are not shown in these figures but would lie well off the curves. The only blend containing the high surface iron was Fe/KClO₄ = 88/12.

As with the UPI burn rate data, an attempt was made to obtain a useful numeric representation of the E-P burn rate data using various empirical equations. As noted previously, the 88/12 E-P blends containing high surface area iron behaved differently than the other blends. This unusual behavior made fitting the data difficult, and a simple linear combination of second degree terms did not produce as good a fit as that obtained for the UPI blends. Various combinations of power and cross terms were applied, usually producing rather convoluted fits. A twelve-term equation was finally found to be acceptable without a great deal of exaggerated convolution exhibited.

RAW IRON POWDER

BLEND LOT NUMBER - PBF-0405-86-14

Bulk Density: 26.7 g/cu.in.

Figure 17 - Percent iron particles greater than given values versus particle size.

Figure 18 - Burn rate of FeK (84/16, E-P) as a function of density (nom rate 77 mm/s, SF = 9.8).

Figure 19 - Burn rate of FeK (86/14, E-P) as a function of density (nom rate 65 mm/s, SF = 11.0).

Figure 20 - Burn rate of FeK (88/12, E-P) as a function of density (nom rate 68.6 mm/s, SF = 14.7).

Figure 21 - Burn rate of FeK (84/16, E-P) as a function of density, surface function = 24.07.

Figure 22 - Burn rate of FeK (86/14, E-P) as a function of density, surface function = 23.7.

Figure 23 - Burn rate of FeK (84/16, E-P) as a function of density (nom rate 109 mm/s, SF = 13.7).

Figure 24 - Burn rate of FeK (86/14, E-P) as a function of density, surface function = 14.9.

Figure 25 - Burn rate of FeK (88/12, E-P) as a function of density, surface function = 23.7.

Figure 26 - Burn rate of FeK (E-P) vs surface function, $T = -54^{\circ}\text{C}$, density = 3.5 g/mL.

Figure 27 - Burn rate of FeK (E-P) vs surface function, density = 3.5 g/mL, $T = 25^{\circ}\text{C}$.

Figure 28 - Burn rate of FeK (E-P) vs surface function, density = 3.5 g/mL, T = 74°C.

Figure 29 - Burn rate of FeK (E-P) vs surface function, density = 4 g/mL, $T = -54^{\circ}\text{C}$.

Figure 30 - Burn rate of FeK vs surface function, density = 4.0 g/mL, $T = 25^{\circ}\text{C}$.

Figure 31 - Burn rate of FeK (E-P) vs surface function, density = 4.0 g/mL, T = 74°C.

Figure 32 - Burn rate of FeK (E-P) vs surface function, density = 4.0 g/mL, $T = 140^{\circ}\text{C}$.

Figure 33 - Burn rate of FeK (E-P) as a function of composition, density = 3.5 g/mL, SF = 23.7, T = 25°C.

Figure 34 - Burn rate of FeK (E-P) as a function of composition, density = 4.0 g/mL, SF = 23.7, T = 25°C.

Figure 35 - Burn rate of FeK (E-P) as a function of composition, density = 3.5 g/mL, SF = 24.

Figure 36 - Burn rate of FeK (E-P) as a function of composition, density = 4.0 g/mL, SF = 24.

Table 3 shows the complete set of E-P burn rate data along with the computed burn rates from the twelve-parameter, empirical fitting equation. The form of the equation for burn rate, R , is

$$R = B(1) + B(2)(\%Fe) + B(3)(\%Fe)^2 + B(4)(SF) + B(5)(SF)^2 + B(6)(SF)^{-1} + B(7)(SF)^{-2} + B(8)(g/mL) + B(9)(g/mL)^2 + B(10)(g/mL)^{-5} + B(11)(T) + B(12)(T)^2$$

and the parametric constants for the fit are

B(1)	=	-3.52038815
B(2)	=	85.5637589
B(3)	=	-.510404738
B(4)	=	-139.985498
B(5)	=	2.06127969
B(6)	=	-35929.1090
B(7)	=	127398.001
B(8)	=	69.4146518
B(9)	=	-13.8866183
B(10)	=	-168.842333
B(11)	=	0.169054658
B(12)	=	0.000344881956

The standard deviation for the fit is 10.7 mm/s.

Typical plots showing the fit are contained in Figures 37 through 39, where the curves are computed from the twelve-parameter equation and the measured burn rate data are represented by discrete points. It is obvious from Figure 39 that the equation should not be used outside the range of the data. Even slightly lower values of surface function than the lowest observed values produce exaggerated errors using this equation. The curves in Figures 37 and 38, computed from the equation, are much shallower than might be expected from the data. Also, when they are compared to the plots in Figures 33 through 36, the indications are again that computed values outside the data range will be in error beyond that indicated by the computed standard deviation from the fit.

**Table 3 - BURN RATE OF FeK (E-P) AS A FUNCTION OF COMPOSITION,
SURFACE FUNCTION, DENSITY, AND TEMPERATURE**

POLYNOMIAL COEFFICIENTS

B(1)=-3.52038815E+00
 B(2)= 8.55637589E+01
 B(3)=-5.10404738E-01
 B(4)=-1.39985498E+02
 B(5)= 2.06127969E+00
 B(6)=-3.59291090E+04
 B(7)= 1.27398001E+05
 B(8)= 6.94146518E+01
 B(9)=-1.38866183E+01
 B(10)=-1.68842333E+02
 B(11)= 1.69054658E-01
 B(12)= 3.44881956E-04

#	% IRON	SURFACE FUNCTION	DENSITY g/ml	TEMPERATURE C	BURN RATE mm/s	CALC	DELTA
1	8.60000000E+01	2.37000000E+01	3.00000000E+00	2.70000000E+01	1.22200000E+02	1.21568227E+02	6.31773455E-01
2	8.60000000E+01	2.37000000E+01	3.00000000E+00	2.70000000E+01	1.24200000E+02	1.21568227E+02	2.63177345E+00
3	8.40000000E+01	2.40700000E+01	4.00000000E+00	7.40000000E+01	1.11500000E+02	1.19851847E+02	-8.35184715E+00
4	8.60000000E+01	2.37000000E+01	3.00000000E+00	1.50000000E+02	1.45200000E+02	1.49870375E+02	-4.67037457E+00
5	8.60000000E+01	2.37000000E+01	3.00000000E+00	1.50000000E+02	1.55500000E+02	1.49870375E+02	5.62962543E+00
6	8.60000000E+01	2.37000000E+01	3.00000000E+00	-5.40000000E+01	1.18400000E+02	1.08629056E+02	9.77094393E+00
7	8.60000000E+01	2.37000000E+01	3.00000000E+00	-5.40000000E+01	9.89900000E+01	1.08629056E+02	-9.63905607E+00
8	8.60000000E+01	2.37000000E+01	3.00000000E+00	-5.40000000E+01	1.07000000E+02	1.08629056E+02	-1.62905607E+00
9	8.60000000E+01	2.37000000E+01	3.00000000E+00	-5.40000000E+01	1.04000000E+02	1.08629056E+02	-4.62905607E+00
10	8.60000000E+01	2.37000000E+01	3.00000000E+00	-5.40000000E+01	1.05000000E+02	1.08629056E+02	-3.62905607E+00
11	8.60000000E+01	2.37000000E+01	3.00000000E+00	7.40000000E+01	1.86300000E+02	1.31150950E+02	5.51490499E+01
12	8.60000000E+01	2.37000000E+01	3.00000000E+00	7.40000000E+01	1.55500000E+02	1.31150950E+02	2.43490499E+01
13	8.60000000E+01	2.37000000E+01	3.00000000E+00	7.40000000E+01	1.34500000E+02	1.31150950E+02	3.34904988E+00
14	8.60000000E+01	2.37000000E+01	3.00000000E+00	7.40000000E+01	1.29200000E+02	1.31150950E+02	-1.95095012E+00
15	8.60000000E+01	2.37000000E+01	3.50000000E+00	2.60000000E+01	1.27700000E+02	1.18187853E+02	9.51214738E+00
16	8.60000000E+01	2.37000000E+01	3.50000000E+00	2.60000000E+01	1.26900000E+02	1.18187853E+02	8.71214738E+00
17	8.60000000E+01	2.37000000E+01	3.50000000E+00	2.60000000E+01	1.26900000E+02	1.18187853E+02	8.71214738E+00

**Table 3 - BURN RATE OF FeK (E-P) AS A FUNCTION OF COMPOSITION,
SURFACE FUNCTION, DENSITY, AND TEMPERATURE (continued)**

18	8.60000000E+01	2.37000000E+01	3.50000000E+00	1.40000000E+02	1.59400000E+02	1.43986630E+02	1.54133702E+01
19	8.60000000E+01	2.37000000E+01	3.50000000E+00	1.40000000E+02	1.57400000E+02	1.43986630E+02	1.34133702E+01
20	8.60000000E+01	2.37000000E+01	3.50000000E+00	-5.40000000E+01	1.08900000E+02	1.05436016E+02	3.46398445E+00
21	8.60000000E+01	2.37000000E+01	3.50000000E+00	-5.40000000E+01	1.10300000E+02	1.05436016E+02	4.86398445E+00
22	8.60000000E+01	2.37000000E+01	3.50000000E+00	7.40000000E+01	1.33600000E+02	1.27957910E+02	5.64209040E+00
23	8.60000000E+01	2.37000000E+01	3.50000000E+00	1.40000000E+02	1.40000000E+02	1.43986630E+02	-3.98662979E+00
24	8.60000000E+01	2.37000000E+01	3.50000000E+00	-1.20000000E+02	9.92700000E+01	9.82390325E+01	1.03096751E+00
25	8.60000000E+01	2.37000000E+01	3.50000000E+00	-1.20000000E+02	1.02400000E+02	9.82390325E+01	4.16096751E+00
26	8.60000000E+01	2.37000000E+01	4.00000000E+00	2.40000000E+01	1.06300000E+02	1.06276619E+02	2.33810786E-02
27	8.60000000E+01	2.37000000E+01	4.00000000E+00	2.40000000E+01	1.09400000E+02	1.06276619E+02	3.12338108E+00
28	8.60000000E+01	2.37000000E+01	4.00000000E+00	1.35000000E+02	1.38000000E+02	1.31128508E+02	6.87149238E+00
29	8.60000000E+01	2.37000000E+01	4.00000000E+00	1.35000000E+02	1.47400000E+02	1.31128508E+02	1.62714924E+01
30	8.60000000E+01	2.37000000E+01	4.00000000E+00	-5.40000000E+01	9.71300000E+01	9.38973794E+01	3.23262064E+00
31	8.60000000E+01	2.37000000E+01	4.00000000E+00	-5.40000000E+01	1.01300000E+02	9.38973794E+01	7.40262064E+00
32	8.60000000E+01	2.37000000E+01	4.00000000E+00	7.40000000E+01	1.21000000E+02	1.16419273E+02	4.58072659E+00
33	8.60000000E+01	2.37000000E+01	4.00000000E+00	7.40000000E+01	1.34500000E+02	1.16419273E+02	1.80807266E+01
34	8.80000000E+01	2.80000000E+01	3.50000000E+00	1.40000000E+02	1.63000000E+02	1.62297948E+02	7.02052119E-01
35	8.80000000E+01	2.80000000E+01	3.50000000E+00	1.40000000E+02	1.64200000E+02	1.62297948E+02	1.90205212E+00
36	8.80000000E+01	2.80000000E+01	3.50000000E+00	-5.40000000E+01	1.06800000E+02	1.23747334E+02	-1.69473336E+01
37	8.80000000E+01	2.80000000E+01	3.50000000E+00	-5.40000000E+01	1.08300000E+02	1.23747334E+02	-1.54473336E+01
38	8.80000000E+01	2.80000000E+01	3.50000000E+00	2.50000000E+01	1.29800000E+02	1.36312527E+02	-6.51252708E+00
39	8.80000000E+01	2.80000000E+01	3.50000000E+00	2.50000000E+01	1.24800000E+02	1.36312527E+02	-1.15125271E+01
40	8.80000000E+01	2.80000000E+01	3.50000000E+00	7.40000000E+01	1.41070000E+02	1.46269228E+02	-5.19922770E+00
41	8.80000000E+01	2.80000000E+01	3.50000000E+00	7.40000000E+01	1.44800000E+02	1.46269228E+02	-1.46922770E+00
42	8.80000000E+01	2.80000000E+01	4.00000000E+00	1.40000000E+02	1.69300000E+02	1.50759312E+02	1.85406883E+01
43	8.80000000E+01	2.80000000E+01	4.00000000E+00	1.40000000E+02	1.75500000E+02	1.50759312E+02	2.47406883E+01
44	8.80000000E+01	2.80000000E+01	4.00000000E+00	2.50000000E+01	1.27000000E+02	1.24773891E+02	2.22610911E+00
45	8.80000000E+01	2.80000000E+01	4.00000000E+00	2.50000000E+01	1.26000000E+02	1.24773891E+02	1.22610911E+00
46	8.80000000E+01	2.80000000E+01	4.00000000E+00	-5.40000000E+01	1.07900000E+02	1.12208697E+02	-4.30869746E+00
47	8.80000000E+01	2.80000000E+01	4.00000000E+00	-5.40000000E+01	1.08500000E+02	1.12208697E+02	-3.70869746E+00
48	8.80000000E+01	2.80000000E+01	4.00000000E+00	7.40000000E+01	1.43300000E+02	1.34730592E+02	8.56940849E+00
49	8.80000000E+01	2.80000000E+01	4.00000000E+00	7.40000000E+01	1.48100000E+02	1.34730592E+02	1.33694085E+01
50	8.40000000E+01	9.80000000E+00	3.50000000E+00	2.70000000E+01	5.47900000E+01	5.62072156E+01	-1.41721557E+00
51	8.40000000E+01	9.80000000E+00	3.50000000E+00	2.70000000E+01	5.40400000E+01	5.62072156E+01	-2.16721557E+00
52	8.40000000E+01	9.80000000E+00	3.50000000E+00	1.40000000E+02	8.06500000E+01	8.18186593E+01	-1.16865934E+00
53	8.40000000E+01	9.80000000E+00	3.50000000E+00	1.40000000E+02	7.66300000E+01	8.18186593E+01	-5.18865934E+00

**Table 3 - BURN RATE OF FeK (E-P) AS A FUNCTION OF COMPOSITION,
SURFACE FUNCTION, DENSITY, AND TEMPERATURE (continued)**

54	8.40000000E+01	9.80000000E+00	3.50000000E+00	-5.40000000E+01	5.06100000E+01	4.32680451E+01	7.34195490E+00
55	8.40000000E+01	9.80000000E+00	3.50000000E+00	-5.40000000E+01	4.86100000E+01	4.32680451E+01	5.34195490E+00
56	8.40000000E+01	9.80000000E+00	3.50000000E+00	-5.40000000E+01	5.04000000E+01	4.32680451E+01	7.13195490E+00
57	8.40000000E+01	9.80000000E+00	3.50000000E+00	7.40000000E+01	6.61900000E+01	6.57899391E+01	4.00060850E-01
58	8.40000000E+01	9.80000000E+00	3.50000000E+00	7.40000000E+01	7.05000000E+01	6.57899391E+01	4.71006085E+00
59	8.40000000E+01	9.80000000E+00	4.00000000E+00	2.80000000E+01	4.52700000E+01	4.48566026E+01	4.13397449E-01
60	8.40000000E+01	9.80000000E+00	4.00000000E+00	2.80000000E+01	4.87800000E+01	4.48566026E+01	3.92339745E+00
61	8.40000000E+01	9.80000000E+00	4.00000000E+00	1.40000000E+02	6.41600000E+01	7.02800232E+01	-6.12002315E+00
62	8.40000000E+01	9.80000000E+00	4.00000000E+00	1.40000000E+02	6.49700000E+01	7.02800232E+01	-5.31002315E+00
63	8.40000000E+01	9.80000000E+00	4.00000000E+00	-5.40000000E+01	4.26500000E+01	3.17294089E+01	1.09205911E+01
64	8.40000000E+01	9.80000000E+00	4.00000000E+00	-5.40000000E+01	4.18600000E+01	3.17294089E+01	1.01305911E+01
65	8.40000000E+01	9.80000000E+00	4.00000000E+00	7.40000000E+01	5.45200000E+01	5.42513030E+01	2.68697035E-01
66	8.40000000E+01	9.80000000E+00	4.00000000E+00	7.40000000E+01	5.45100000E+01	5.42513030E+01	2.58697035E-01
67	8.60000000E+01	1.10000000E+01	3.50000000E+00	2.50000000E+01	5.66800000E+01	6.32093077E+01	-6.52930765E+00
68	8.60000000E+01	1.10000000E+01	3.50000000E+00	2.50000000E+01	5.96100000E+01	6.32093077E+01	-3.59930765E+00
69	8.60000000E+01	1.10000000E+01	3.50000000E+00	1.40000000E+02	7.38100000E+01	8.91947285E+01	-1.53847285E+01
70	8.60000000E+01	1.10000000E+01	3.50000000E+00	1.40000000E+02	7.31600000E+01	8.91947285E+01	-1.60347285E+01
71	8.60000000E+01	1.10000000E+01	3.50000000E+00	-5.40000000E+01	5.01100000E+01	5.06441142E+01	-5.34114219E-01
72	8.60000000E+01	1.10000000E+01	3.50000000E+00	-5.40000000E+01	5.11000000E+01	5.06441142E+01	4.55885781E-01
73	8.60000000E+01	1.10000000E+01	3.50000000E+00	7.40000000E+01	6.35100000E+01	7.31660083E+01	-9.65600827E+00
74	8.60000000E+01	1.10000000E+01	3.50000000E+00	7.40000000E+01	6.28600000E+01	7.31660083E+01	-1.03060083E+01
75	8.60000000E+01	1.10000000E+01	4.00000000E+00	2.50000000E+01	4.89500000E+01	5.16706715E+01	-2.72067147E+00
76	8.60000000E+01	1.10000000E+01	4.00000000E+00	2.50000000E+01	4.96300000E+01	5.16706715E+01	-2.04067147E+00
77	8.60000000E+01	1.10000000E+01	4.00000000E+00	1.40000000E+02	6.83100000E+01	7.76560923E+01	-9.34609228E+00
78	8.60000000E+01	1.10000000E+01	4.00000000E+00	1.40000000E+02	6.47600000E+01	7.76560923E+01	-1.28960923E+01
79	8.60000000E+01	1.10000000E+01	4.00000000E+00	-5.40000000E+01	4.52300000E+01	3.91054780E+01	6.12452197E+00
80	8.60000000E+01	1.10000000E+01	4.00000000E+00	-5.40000000E+01	4.20200000E+01	3.91054780E+01	2.91452197E+00
81	8.60000000E+01	1.10000000E+01	4.00000000E+00	7.40000000E+01	5.82400000E+01	6.16273721E+01	-3.38737209E+00
82	8.60000000E+01	1.10000000E+01	4.00000000E+00	7.40000000E+01	5.77300000E+01	6.16273721E+01	-3.89737209E+00
83	8.80000000E+01	1.47000000E+01	3.00000000E+00	7.40000000E+01	9.78700000E+01	1.06735891E+02	-8.86589088E+00
84	8.80000000E+01	1.47000000E+01	3.00000000E+00	7.40000000E+01	1.00400000E+02	1.06735891E+02	-6.33589088E+00
85	8.80000000E+01	1.47000000E+01	3.00000000E+00	7.40000000E+01	9.64000000E+01	1.06735891E+02	-1.03358909E+01
86	8.80000000E+01	1.47000000E+01	3.00000000E+00	7.40000000E+01	1.02300000E+02	1.06735891E+02	-4.43589088E+00
87	8.80000000E+01	1.47000000E+01	3.00000000E+00	7.40000000E+01	1.04080000E+02	1.06735891E+02	-2.65589088E+00
88	8.80000000E+01	1.47000000E+01	3.00000000E+00	7.40000000E+01	1.02200000E+02	1.06735891E+02	-4.53589088E+00
89	8.80000000E+01	1.47000000E+01	3.00000000E+00	2.50000000E+01	8.76000000E+01	9.67791903E+01	-9.17919026E+00

**Table 3 - BURN RATE OF FeK (E-P) AS A FUNCTION OF COMPOSITION,
SURFACE FUNCTION, DENSITY, AND TEMPERATURE (continued)**

90	8.8000000E+01	1.4700000E+01	3.0000000E+00	2.5000000E+01	8.7800000E+01	9.67791903E+01	-8.97919026E+00
91	8.8000000E+01	1.4700000E+01	3.0000000E+00	2.5000000E+01	8.7700000E+01	9.67791903E+01	-9.07919026E+00
92	8.8000000E+01	1.4700000E+01	3.0000000E+00	2.5000000E+01	8.7700000E+01	9.67791903E+01	-9.07919026E+00
93	8.8000000E+01	1.4700000E+01	3.0000000E+00	2.5000000E+01	8.6930000E+01	9.67791903E+01	-9.84919026E+00
94	8.8000000E+01	1.4700000E+01	3.0000000E+00	-5.4000000E+01	7.4410000E+01	8.42139968E+01	-9.80399683E+00
95	8.8000000E+01	1.4700000E+01	3.0000000E+00	-5.4000000E+01	7.4040000E+01	8.42139968E+01	-1.01739968E+01
96	8.8000000E+01	1.4700000E+01	3.0000000E+00	1.4600000E+02	1.3100000E+02	1.24370756E+02	6.62924355E+00
97	8.8000000E+01	1.4700000E+01	3.5000000E+00	2.5000000E+01	8.6930000E+01	9.35861497E+01	-6.65614974E+00
98	8.8000000E+01	1.4700000E+01	3.5000000E+00	2.5000000E+01	8.9180000E+01	9.35861497E+01	-4.40614974E+00
99	8.8000000E+01	1.4700000E+01	3.5000000E+00	2.5000000E+01	9.4100000E+01	9.35861497E+01	5.13850264E-01
100	8.8000000E+01	1.4700000E+01	3.5000000E+00	7.4000000E+01	1.0375000E+02	1.03542850E+02	2.07149644E-01
101	8.8000000E+01	1.4700000E+01	3.5000000E+00	7.4000000E+01	1.0590000E+02	1.03542850E+02	2.35714964E+00
102	8.8000000E+01	1.4700000E+01	3.5000000E+00	-5.4000000E+01	7.7590000E+01	8.10209563E+01	-3.43095630E+00
103	8.8000000E+01	1.4700000E+01	3.5000000E+00	-5.4000000E+01	7.8280000E+01	8.10209563E+01	-2.74095630E+00
104	8.8000000E+01	1.4700000E+01	3.5000000E+00	1.2500000E+02	1.1500000E+02	1.15664845E+02	-6.64844894E-01
105	8.8000000E+01	1.4700000E+01	3.5000000E+00	1.2500000E+02	1.2180000E+02	1.15664845E+02	6.13515511E+00
106	8.8000000E+01	1.4700000E+01	4.0000000E+00	1.5800000E+02	1.1790000E+02	1.12925865E+02	4.97413498E+00
107	8.8000000E+01	1.4700000E+01	4.0000000E+00	1.5800000E+02	1.2220000E+02	1.12925865E+02	9.27413498E+00
108	8.8000000E+01	1.4700000E+01	4.0000000E+00	-5.4000000E+01	7.1700000E+01	6.94823201E+01	2.21767988E+00
109	8.8000000E+01	1.4700000E+01	4.0000000E+00	-5.4000000E+01	7.2570000E+01	6.94823201E+01	3.08767988E+00
110	8.8000000E+01	1.4700000E+01	4.0000000E+00	7.4000000E+01	9.4460000E+01	9.20042142E+01	2.45578583E+00
111	8.8000000E+01	1.4700000E+01	4.0000000E+00	7.4000000E+01	9.8220000E+01	9.20042142E+01	6.21578583E+00
112	8.8000000E+01	1.4700000E+01	4.0000000E+00	2.5000000E+01	8.5550000E+01	8.20475136E+01	3.50248645E+00
113	8.8000000E+01	1.4700000E+01	4.0000000E+00	2.4200000E+01	8.5930000E+01	8.18986953E+01	4.03130473E+00
114	8.4000000E+01	1.3700000E+01	4.0000000E+00	2.5000000E+01	7.4020000E+01	8.31987434E+01	-9.17874343E+00
115	8.4000000E+01	1.3700000E+01	4.0000000E+00	2.5000000E+01	7.8930000E+01	8.31987434E+01	-4.26874343E+00
116	8.4000000E+01	1.3700000E+01	4.0000000E+00	1.4000000E+02	1.0420000E+02	1.09184164E+02	-4.98416423E+00
117	8.4000000E+01	1.3700000E+01	4.0000000E+00	1.4000000E+02	1.1560000E+02	1.09184164E+02	6.41583577E+00
118	8.4000000E+01	1.3700000E+01	4.0000000E+00	-5.4000000E+01	7.2140000E+01	7.06335500E+01	1.50645001E+00
119	8.4000000E+01	1.3700000E+01	4.0000000E+00	-5.4000000E+01	6.8670000E+01	7.06335500E+01	-1.96354999E+00
120	8.4000000E+01	1.3700000E+01	4.0000000E+00	7.4000000E+01	9.0790000E+01	9.31554440E+01	-2.36544405E+00
121	8.4000000E+01	1.3700000E+01	4.0000000E+00	7.4000000E+01	9.9320000E+01	9.31554440E+01	6.16455595E+00
122	8.4000000E+01	1.3700000E+01	5.0000000E+00	2.7000000E+01	4.1260000E+01	3.69203868E+01	4.33961315E+00
123	8.4000000E+01	1.3700000E+01	5.0000000E+00	2.7000000E+01	4.5630000E+01	3.69203868E+01	8.70961315E+00
124	8.4000000E+01	1.3700000E+01	5.0000000E+00	1.4000000E+02	6.9620000E+01	6.25318306E+01	7.08816939E+00
125	8.4000000E+01	1.3700000E+01	5.0000000E+00	1.4000000E+02	6.5100000E+01	6.25318306E+01	2.56816939E+00

**Table 3 - BURN RATE OF FeK (E-P) AS A FUNCTION OF COMPOSITION,
SURFACE FUNCTION, DENSITY, AND TEMPERATURE (continued)**

126	8.40000000E+01	1.37000000E+01	5.00000000E+00	-5.40000000E+01	3.83700000E+01	2.39812164E+01	1.43887836E+01
127	8.40000000E+01	1.37000000E+01	5.00000000E+00	-5.40000000E+01	3.86300000E+01	2.39812164E+01	1.46487836E+01
128	8.40000000E+01	1.37000000E+01	5.00000000E+00	7.40000000E+01	5.92700000E+01	4.65031104E+01	1.27668896E+01
129	8.40000000E+01	1.37000000E+01	5.00000000E+00	7.40000000E+01	5.77400000E+01	4.65031104E+01	1.12368896E+01
130	8.40000000E+01	1.37000000E+01	3.30000000E+00	2.63000000E+01	9.76300000E+01	9.72883993E+01	3.41600682E-01
131	8.40000000E+01	1.30000000E+01	3.30000000E+00	2.63000000E+01	1.05030000E+02	9.06041544E+01	1.44258456E+01
132	8.40000000E+01	1.37000000E+01	3.30000000E+00	1.40000000E+02	1.31350000E+02	1.23031049E+02	8.31895111E+00
133	8.40000000E+01	1.37000000E+01	3.30000000E+00	1.40000000E+02	1.28810000E+02	1.23031049E+02	5.77895111E+00
134	8.40000000E+01	1.37000000E+01	3.30000000E+00	-5.40000000E+01	9.21900000E+01	8.44804346E+01	7.70956535E+00
135	8.40000000E+01	1.37000000E+01	3.30000000E+00	-5.40000000E+01	9.50300000E+01	8.44804346E+01	1.05495654E+01
136	8.40000000E+01	1.37000000E+01	3.30000000E+00	7.40000000E+01	1.12400000E+02	1.07002329E+02	5.39767130E+00
137	8.40000000E+01	1.37000000E+01	3.30000000E+00	7.40000000E+01	1.16200000E+02	1.07002329E+02	9.19767130E+00
138	8.40000000E+01	1.37000000E+01	3.50000000E+00	2.59000000E+01	9.46800000E+01	9.49053278E+01	-2.25327845E-01
139	8.40000000E+01	1.37000000E+01	3.50000000E+00	2.59000000E+01	1.00330000E+02	9.49053278E+01	5.42467215E+00
140	8.40000000E+01	1.37000000E+01	3.50000000E+00	1.40000000E+02	1.22220000E+02	1.20722800E+02	1.49719958E+00
141	8.40000000E+01	1.37000000E+01	3.50000000E+00	1.40000000E+02	1.27160000E+02	1.20722800E+02	6.43719958E+00
142	8.40000000E+01	1.37000000E+01	3.50000000E+00	-5.40000000E+01	8.73400000E+01	8.21721862E+01	5.16781382E+00
143	8.40000000E+01	1.37000000E+01	3.50000000E+00	-5.40000000E+01	8.83700000E+01	8.21721862E+01	6.19781382E+00
144	8.40000000E+01	1.37000000E+01	3.50000000E+00	7.40000000E+01	1.13400000E+02	1.04694080E+02	8.70591977E+00
145	8.40000000E+01	1.37000000E+01	3.50000000E+00	7.40000000E+01	1.11300000E+02	1.04694080E+02	6.60591977E+00
146	8.40000000E+01	1.37000000E+01	2.50000000E+00	2.33000000E+01	9.65300000E+01	9.17914824E+01	4.73851763E+00
147	8.40000000E+01	1.37000000E+01	2.50000000E+00	2.33000000E+01	1.04700000E+02	9.17914824E+01	1.29085176E+01
148	8.40000000E+01	1.37000000E+01	2.50000000E+00	1.40000000E+02	5.40400000E+01	1.18092614E+02	-6.40526144E+01
149	8.40000000E+01	1.37000000E+01	2.50000000E+00	1.40000000E+02	5.51400000E+01	1.18092614E+02	-6.29526144E+01
150	8.40000000E+01	1.37000000E+01	2.50000000E+00	-5.40000000E+01	9.57700000E+01	7.95420001E+01	1.62279999E+01
151	8.40000000E+01	1.37000000E+01	2.50000000E+00	-5.40000000E+01	9.80700000E+01	7.95420001E+01	1.85279999E+01
152	8.40000000E+01	1.37000000E+01	2.50000000E+00	7.40000000E+01	1.15900000E+02	1.02063894E+02	1.38361058E+01
153	8.40000000E+01	1.37000000E+01	2.50000000E+00	7.40000000E+01	1.26300000E+02	1.02063894E+02	2.42361058E+01
154	8.40000000E+01	1.37000000E+01	2.50000000E+00	7.40000000E+01	1.14600000E+02	1.02063894E+02	1.25361058E+01
155	8.40000000E+01	1.37000000E+01	2.50000000E+00	7.40000000E+01	1.26200000E+02	1.02063894E+02	2.41361058E+01
156	8.40000000E+01	1.37000000E+01	3.00000000E+00	2.50000000E+01	9.99200000E+01	9.79304201E+01	1.98957986E+00
157	8.40000000E+01	1.37000000E+01	3.00000000E+00	2.50000000E+01	1.04010000E+02	9.79304201E+01	6.07957986E+00
158	8.40000000E+01	1.37000000E+01	3.00000000E+00	1.40000000E+02	1.27000000E+02	1.23915841E+02	3.08415906E+00
159	8.40000000E+01	1.37000000E+01	3.00000000E+00	1.40000000E+02	1.30000000E+02	1.23915841E+02	6.08415906E+00
160	8.40000000E+01	1.37000000E+01	3.00000000E+00	-5.40000000E+01	9.57700000E+01	8.53652267E+01	1.04047733E+01

**Table 3 - BURN RATE OF FeK (E-P) AS A FUNCTION OF COMPOSITION,
SURFACE FUNCTION, DENSITY, AND TEMPERATURE (continued)**

161	8.40000000E+01	1.37000000E+01	3.00000000E+00	-5.40000000E+01	9.80700000E+01	8.53652267E+01	1.27047733E+01
162	8.40000000E+01	1.37000000E+01	3.00000000E+00	7.40000000E+01	1.14500000E+02	1.07887121E+02	6.61287924E+00
163	8.40000000E+01	1.37000000E+01	3.00000000E+00	7.40000000E+01	1.21000000E+02	1.07887121E+02	1.31128792E+01
164	8.60000000E+01	1.49000000E+01	2.50000000E+00	7.40000000E+01	1.08700000E+02	1.08698260E+02	1.74040675E-03
165	8.60000000E+01	1.49000000E+01	2.50000000E+00	7.40000000E+01	1.21600000E+02	1.08698260E+02	1.29017404E+01
166	8.60000000E+01	1.49000000E+01	2.50000000E+00	7.40000000E+01	1.07400000E+02	1.08698260E+02	-1.29825959E+00
167	8.60000000E+01	1.49000000E+01	2.50000000E+00	7.40000000E+01	1.10600000E+02	1.08698260E+02	1.90174041E+00
168	8.60000000E+01	1.49000000E+01	3.00000000E+00	7.40000000E+01	1.13800000E+02	1.14521486E+02	-7.21486181E-01
169	8.60000000E+01	1.49000000E+01	2.50000000E+00	7.40000000E+01	1.06300000E+02	1.08698260E+02	-2.39825959E+00
170	8.60000000E+01	1.49000000E+01	2.50000000E+00	7.40000000E+01	1.06600000E+02	1.08698260E+02	-2.09825959E+00
171	8.60000000E+01	1.49000000E+01	3.00000000E+00	7.40000000E+01	1.16100000E+02	1.14521486E+02	1.57851382E+00
172	8.60000000E+01	1.49000000E+01	3.00000000E+00	7.40000000E+01	1.14500000E+02	1.14521486E+02	-2.14861807E-02
173	8.60000000E+01	1.49000000E+01	3.00000000E+00	7.40000000E+01	1.25100000E+02	1.14521486E+02	1.05785138E+01
174	8.60000000E+01	1.49000000E+01	3.00000000E+00	7.40000000E+01	1.11200000E+02	1.14521486E+02	-3.32148618E+00
175	8.60000000E+01	1.49000000E+01	3.00000000E+00	7.40000000E+01	1.13300000E+02	1.14521486E+02	-1.22148618E+00
176	8.60000000E+01	1.49000000E+01	3.30000000E+00	7.40000000E+01	1.14500000E+02	1.13636694E+02	8.63305871E-01
177	8.60000000E+01	1.49000000E+01	3.30000000E+00	7.40000000E+01	1.14400000E+02	1.13636694E+02	7.63305871E-01
178	8.60000000E+01	1.49000000E+01	3.30000000E+00	7.40000000E+01	1.10600000E+02	1.13636694E+02	-3.03669413E+00
179	8.60000000E+01	1.49000000E+01	3.30000000E+00	7.40000000E+01	1.16700000E+02	1.13636694E+02	3.06330587E+00
180	8.60000000E+01	1.49000000E+01	3.30000000E+00	7.40000000E+01	1.11600000E+02	1.13636694E+02	-2.03669413E+00
181	8.60000000E+01	1.49000000E+01	3.30000000E+00	7.40000000E+01	1.13100000E+02	1.13636694E+02	-5.36694129E-01
182	8.60000000E+01	1.49000000E+01	3.50000000E+00	7.40000000E+01	1.12000000E+02	1.11328446E+02	6.71554345E-01
183	8.60000000E+01	1.49000000E+01	3.50000000E+00	7.40000000E+01	1.14600000E+02	1.11328446E+02	3.27155434E+00
184	8.60000000E+01	1.49000000E+01	3.50000000E+00	7.40000000E+01	1.12600000E+02	1.11328446E+02	1.27155434E+00
185	8.60000000E+01	1.49000000E+01	3.50000000E+00	7.40000000E+01	1.15000000E+02	1.11328446E+02	3.67155434E+00
186	8.60000000E+01	1.49000000E+01	3.50000000E+00	7.40000000E+01	1.08800000E+02	1.11328446E+02	-2.52844566E+00
187	8.60000000E+01	1.49000000E+01	3.50000000E+00	7.40000000E+01	1.13100000E+02	1.11328446E+02	1.77155434E+00
188	8.60000000E+01	1.49000000E+01	4.00000000E+00	7.40000000E+01	9.22000000E+01	9.97898095E+01	-7.58980947E+00
189	8.60000000E+01	1.49000000E+01	4.00000000E+00	7.40000000E+01	9.47000000E+01	9.97898095E+01	-5.08980947E+00
190	8.60000000E+01	1.49000000E+01	4.00000000E+00	7.40000000E+01	9.70000000E+01	9.97898095E+01	-2.78980947E+00
191	8.60000000E+01	1.49000000E+01	4.00000000E+00	7.40000000E+01	9.87000000E+01	9.97898095E+01	-1.08980947E+00
192	8.60000000E+01	1.49000000E+01	4.00000000E+00	7.40000000E+01	9.52200000E+01	9.97898095E+01	-4.56980947E+00
193	8.60000000E+01	1.49000000E+01	4.00000000E+00	7.40000000E+01	9.33000000E+01	9.97898095E+01	-6.48980947E+00
194	8.60000000E+01	1.49000000E+01	5.00000000E+00	7.40000000E+01	3.86500000E+01	5.31374759E+01	-1.44874759E+01
195	8.60000000E+01	1.49000000E+01	5.00000000E+00	7.40000000E+01	3.79000000E+01	5.31374759E+01	-1.52374759E+01

**Table 3 - BURN RATE OF FeK (E-P) AS A FUNCTION OF COMPOSITION,
SURFACE FUNCTION, DENSITY, AND TEMPERATURE (continued)**

196	8.60000000E+01	1.49000000E+01	5.00000000E+00	7.40000000E+01	4.08000000E+01	5.31374759E+01	-1.23374759E+01
197	8.60000000E+01	1.49000000E+01	5.00000000E+00	7.40000000E+01	3.91600000E+01	5.31374759E+01	-1.39774759E+01
198	8.60000000E+01	1.49000000E+01	2.50000000E+00	-5.40000000E+01	8.37000000E+01	8.61763655E+01	-2.47636554E+00
199	8.60000000E+01	1.49000000E+01	2.50000000E+00	-5.40000000E+01	8.97000000E+01	8.61763655E+01	3.52363446E+00
200	8.60000000E+01	1.49000000E+01	2.50000000E+00	-5.40000000E+01	8.33400000E+01	8.61763655E+01	-2.83636554E+00
201	8.60000000E+01	1.49000000E+01	3.00000000E+00	-5.40000000E+01	9.30600000E+01	9.19995921E+01	1.06040787E+00
202	8.60000000E+01	1.49000000E+01	3.00000000E+00	-5.40000000E+01	9.20000000E+01	9.19995921E+01	4.07873992E-04
203	8.60000000E+01	1.49000000E+01	3.00000000E+00	-5.40000000E+01	9.01500000E+01	9.19995921E+01	-1.84959213E+00
204	8.60000000E+01	1.49000000E+01	3.30000000E+00	-5.40000000E+01	9.05400000E+01	9.11148001E+01	-5.74800075E-01
205	8.60000000E+01	1.49000000E+01	3.30000000E+00	-5.40000000E+01	8.81800000E+01	9.11148001E+01	-2.93480007E+00
206	8.60000000E+01	1.49000000E+01	3.30000000E+00	-5.40000000E+01	9.06700000E+01	9.11148001E+01	-4.44800075E-01
207	8.60000000E+01	1.49000000E+01	3.50000000E+00	-5.40000000E+01	8.88400000E+01	8.88065516E+01	3.34483992E-02
208	8.60000000E+01	1.49000000E+01	3.50000000E+00	-5.40000000E+01	8.85300000E+01	8.88065516E+01	-2.76551601E-01
209	8.60000000E+01	1.49000000E+01	3.50000000E+00	-5.40000000E+01	8.72300000E+01	8.88065516E+01	-1.57655160E+00
210	8.60000000E+01	1.49000000E+01	4.00000000E+00	-5.40000000E+01	7.27300000E+01	7.72679154E+01	-4.53791542E+00
211	8.60000000E+01	1.49000000E+01	4.00000000E+00	-5.40000000E+01	7.43600000E+01	7.72679154E+01	-2.90791542E+00
212	8.60000000E+01	1.49000000E+01	4.00000000E+00	-5.40000000E+01	7.41700000E+01	7.72679154E+01	-3.09791542E+00
213	8.60000000E+01	1.49000000E+01	5.00000000E+00	-5.40000000E+01	3.03900000E+01	3.06155818E+01	-2.25581798E-01
214	8.60000000E+01	1.49000000E+01	5.00000000E+00	-5.40000000E+01	2.94400000E+01	3.06155818E+01	-1.17558180E+00
215	8.60000000E+01	1.49000000E+01	2.50000000E+00	2.50000000E+01	1.00100000E+02	9.87415590E+01	1.35844103E+00
216	8.60000000E+01	1.49000000E+01	2.50000000E+00	2.50000000E+01	9.98300000E+01	9.87415590E+01	1.08844103E+00
217	8.60000000E+01	1.49000000E+01	2.50000000E+00	2.50000000E+01	9.08100000E+01	9.87415590E+01	-7.93155897E+00
218	8.60000000E+01	1.49000000E+01	3.00000000E+00	2.50000000E+01	1.00400000E+02	1.04564786E+02	-4.16478556E+00
219	8.60000000E+01	1.49000000E+01	3.00000000E+00	2.50000000E+01	1.03100000E+02	1.04564786E+02	-1.46478556E+00
220	8.60000000E+01	1.49000000E+01	3.00000000E+00	2.50000000E+01	1.02900000E+02	1.04564786E+02	-1.66478556E+00
221	8.60000000E+01	1.49000000E+01	3.30000000E+00	2.50000000E+01	1.02100000E+02	1.03679994E+02	-1.57999351E+00
222	8.60000000E+01	1.49000000E+01	3.30000000E+00	2.50000000E+01	1.04800000E+02	1.03679994E+02	1.12000649E+00
223	8.60000000E+01	1.49000000E+01	3.30000000E+00	2.50000000E+01	1.00400000E+02	1.03679994E+02	-3.27999351E+00
224	8.60000000E+01	1.49000000E+01	3.50000000E+00	2.50000000E+01	1.03100000E+02	1.01371745E+02	1.72825496E+00
225	8.60000000E+01	1.49000000E+01	3.50000000E+00	2.50000000E+01	1.07700000E+02	1.01371745E+02	6.32825496E+00
226	8.60000000E+01	1.49000000E+01	3.50000000E+00	2.50000000E+01	1.01300000E+02	1.01371745E+02	-7.17450361E-02
227	8.60000000E+01	1.49000000E+01	4.00000000E+00	2.50000000E+01	8.47000000E+01	8.98331089E+01	-5.13310885E+00
228	8.60000000E+01	1.49000000E+01	4.00000000E+00	2.50000000E+01	8.70000000E+01	8.98331089E+01	-2.83310885E+00
229	8.60000000E+01	1.49000000E+01	4.00000000E+00	2.50000000E+01	8.21200000E+01	8.98331089E+01	-7.71310885E+00
230	8.60000000E+01	1.49000000E+01	5.00000000E+00	3.00000000E+01	3.62200000E+01	4.41208911E+01	-7.90089106E+00

**Table 3 - BURN RATE OF FeK (E-P) AS A FUNCTION OF COMPOSITION,
SURFACE FUNCTION, DENSITY, AND TEMPERATURE (continued)**

231	8.60000000E+01	1.49000000E+01	5.00000000E+00	3.00000000E+01	3.80200000E+01	4.41208911E+01	-6.10089106E+00
232	8.60000000E+01	1.49000000E+01	5.00000000E+00	3.00000000E+01	4.41500000E+01	4.41208911E+01	2.91089377E-02
233	8.80000000E+01	2.37000000E+01	3.50000000E+00	7.40000000E+01	1.20300000E+02	1.21464579E+02	-1.16457852E+00
234	8.80000000E+01	2.37000000E+01	3.50000000E+00	7.40000000E+01	1.24000000E+02	1.21464579E+02	2.53542148E+00
235	8.80000000E+01	2.37000000E+01	3.50000000E+00	-5.40000000E+01	8.94000000E+01	9.89426845E+01	-9.54268446E+00
236	8.80000000E+01	2.37000000E+01	3.50000000E+00	-5.40000000E+01	9.38000000E+01	9.89426845E+01	-5.14268446E+00
237	8.80000000E+01	2.37000000E+01	3.50000000E+00	2.50000000E+01	1.12600000E+02	1.11507878E+02	1.09212210E+00
238	8.80000000E+01	2.37000000E+01	3.50000000E+00	2.50000000E+01	1.14200000E+02	1.11507878E+02	2.69212210E+00
239	8.80000000E+01	2.37000000E+01	3.50000000E+00	1.40000000E+02	1.42100000E+02	1.37493299E+02	4.60670129E+00
240	8.80000000E+01	2.37000000E+01	3.50000000E+00	1.40000000E+02	1.44000000E+02	1.37493299E+02	6.50670129E+00
241	8.80000000E+01	2.37000000E+01	4.00000000E+00	7.40000000E+01	1.17300000E+02	1.09925942E+02	7.37405767E+00
242	8.80000000E+01	2.37000000E+01	4.00000000E+00	7.40000000E+01	1.24400000E+02	1.09925942E+02	1.44740577E+01
243	8.80000000E+01	2.37000000E+01	4.00000000E+00	-5.40000000E+01	8.85000000E+01	8.74040483E+01	1.09595172E+00
244	8.80000000E+01	2.37000000E+01	4.00000000E+00	-5.40000000E+01	9.02000000E+01	8.74040483E+01	2.79595172E+00
245	8.80000000E+01	2.37000000E+01	4.00000000E+00	2.60000000E+01	1.12400000E+02	1.00155885E+02	1.22441146E+01
246	8.80000000E+01	2.37000000E+01	4.00000000E+00	2.60000000E+01	1.14300000E+02	1.00155885E+02	1.41441146E+01
247	8.80000000E+01	2.37000000E+01	4.00000000E+00	2.60000000E+01	8.79000000E+01	1.00155885E+02	-1.22558854E+01
248	8.80000000E+01	2.37000000E+01	4.00000000E+00	1.42000000E+02	1.37100000E+02	1.26487285E+02	1.06127147E+01
249	8.80000000E+01	2.37000000E+01	4.00000000E+00	1.42000000E+02	1.42400000E+02	1.26487285E+02	1.59127147E+01
250	8.80000000E+01	2.37000000E+01	5.00000000E+00	7.40000000E+01	5.80200000E+01	6.32736087E+01	-5.25360872E+00
251	8.80000000E+01	2.37000000E+01	5.00000000E+00	7.40000000E+01	5.13300000E+01	6.32736087E+01	-1.19436087E+01
252	8.80000000E+01	2.37000000E+01	5.00000000E+00	7.40000000E+01	7.00400000E+01	6.32736087E+01	6.76639128E+00
253	8.80000000E+01	2.37000000E+01	5.00000000E+00	7.40000000E+01	5.05500000E+01	6.32736087E+01	-1.27236087E+01
254	8.80000000E+01	2.37000000E+01	5.00000000E+00	-5.40000000E+01	3.68000000E+01	4.07517147E+01	-3.95171466E+00
255	8.80000000E+01	2.37000000E+01	5.00000000E+00	-5.40000000E+01	4.84100000E+01	4.07517147E+01	7.65828534E+00
256	8.80000000E+01	2.37000000E+01	5.00000000E+00	-5.40000000E+01	5.10000000E+01	4.07517147E+01	1.02482853E+01
257	8.80000000E+01	2.37000000E+01	5.00000000E+00	-5.40000000E+01	3.96000000E+01	4.07517147E+01	-1.15171466E+00
258	8.80000000E+01	2.37000000E+01	5.00000000E+00	2.50000000E+01	5.45700000E+01	5.33169081E+01	1.25309190E+00
259	8.80000000E+01	2.37000000E+01	5.00000000E+00	2.50000000E+01	6.82800000E+01	5.33169081E+01	1.49630919E+01
260	8.80000000E+01	2.37000000E+01	5.00000000E+00	2.50000000E+01	3.70000000E+01	5.33169081E+01	-1.63169081E+01
261	8.80000000E+01	2.37000000E+01	5.00000000E+00	1.50000000E+02	8.79000000E+01	8.19930332E+01	5.90696684E+00
262	8.40000000E+01	2.40700000E+01	3.00000000E+00	2.50000000E+01	1.14300000E+02	1.24626823E+02	-1.03268232E+01
263	8.40000000E+01	2.40700000E+01	3.00000000E+00	2.50000000E+01	1.16100000E+02	1.24626823E+02	-8.52682324E+00
264	8.40000000E+01	2.40700000E+01	3.00000000E+00	1.18000000E+02	1.38900000E+02	1.44935492E+02	-6.03549158E+00
265	8.40000000E+01	2.40700000E+01	3.00000000E+00	1.18000000E+02	1.39800000E+02	1.44935492E+02	-5.13549158E+00

**Table 3 - BURN RATE OF FeK (E-P) AS A FUNCTION OF COMPOSITION,
SURFACE FUNCTION, DENSITY, AND TEMPERATURE (continued)**

266	8.40000000E+01	2.40700000E+01	3.00000000E+00	-5.40000000E+01	1.04900000E+02	1.12061630E+02	-7.16162980E+00
267	8.40000000E+01	2.40700000E+01	3.00000000E+00	-5.40000000E+01	1.04900000E+02	1.12061630E+02	-7.16162980E+00
268	8.40000000E+01	2.40700000E+01	3.00000000E+00	7.40000000E+01	1.23200000E+02	1.34583524E+02	-1.13835239E+01
269	8.40000000E+01	2.40700000E+01	3.00000000E+00	7.40000000E+01	1.32900000E+02	1.34583524E+02	-1.68352386E+00
270	8.40000000E+01	2.40700000E+01	3.50000000E+00	2.50000000E+01	1.06500000E+02	1.21433783E+02	-1.49337827E+01
271	8.40000000E+01	2.40700000E+01	3.50000000E+00	2.50000000E+01	1.15500000E+02	1.21433783E+02	-5.93378271E+00
272	8.40000000E+01	2.40700000E+01	3.50000000E+00	1.25000000E+02	1.34660000E+02	1.43512478E+02	-8.85247787E+00
273	8.40000000E+01	2.40700000E+01	3.50000000E+00	1.25000000E+02	1.46240000E+02	1.43512478E+02	2.72752213E+00
274	8.40000000E+01	2.40700000E+01	3.50000000E+00	-5.40000000E+01	9.87100000E+01	1.08868589E+02	-1.01585893E+01
275	8.40000000E+01	2.40700000E+01	3.50000000E+00	-5.40000000E+01	9.44900000E+01	1.08868589E+02	-1.43785893E+01
276	8.40000000E+01	2.40700000E+01	3.50000000E+00	7.40000000E+01	1.25400000E+02	1.31390483E+02	-5.99048333E+00
277	8.40000000E+01	2.40700000E+01	4.00000000E+00	2.50000000E+01	9.13600000E+01	1.09895147E+02	-1.85351465E+01
278	8.40000000E+01	2.40700000E+01	4.00000000E+00	2.50000000E+01	9.42000000E+01	1.09895147E+02	-1.56951465E+01
279	8.40000000E+01	2.40700000E+01	4.00000000E+00	1.37000000E+02	1.28100000E+02	1.35086806E+02	-6.98680645E+00
280	8.40000000E+01	2.40700000E+01	4.00000000E+00	1.37000000E+02	1.14300000E+02	1.35086806E+02	-2.07868065E+01
281	8.40000000E+01	2.40700000E+01	4.00000000E+00	1.20000000E+02	1.14700000E+02	1.30706088E+02	-1.60060880E+01
282	8.40000000E+01	2.40700000E+01	4.00000000E+00	-5.40000000E+01	7.03200000E+01	9.73299531E+01	-2.70099531E+01
283	8.40000000E+01	2.40700000E+01	4.00000000E+00	-5.40000000E+01	7.60000000E+01	9.73299531E+01	-2.13299531E+01
284	8.40000000E+01	2.40700000E+01	4.00000000E+00	7.40000000E+01	1.11200000E+02	1.19851847E+02	-8.65184715E+00

SIGMA = 10.6981419293

Figure 37 - Burn rate of FeK (E-P) as a function of composition, surface function = 14, density = 3.5 g/mL.

Figure 38 - Burn rate of FeK (E-P) as a function of composition, surface function = 24, density = 3.5 g/mL.

Figure 39 - Burn rate of FeK (E-P) versus surface function, $T = 25^{\circ}\text{C}$, density = 3.5 g/mL.

Conclusions

A technique for measuring burn rates of pyrotechnic heat sources producing moderate amounts of gas has been developed using a high speed video motion analysis system. The system has been shown to be fast, inexpensive to operate, easy to use and to produce reliable results. The system promises to be useful in material development, as a material product acceptance tool, and in material and device quality assurance. The limiting maximum rate is approximately 10 to 100 meters per second, depending on pellet dimensions and resolution required. Other limiting factors are the requirement that sufficient light be emitted at the burn front to allow detection, that smoke or particles are not sufficient to obscure the light, and that the compacted material does not disintegrate during measurement. The system has been used here for determining burn rates of heat source pellets of material burning at relatively slow rates.

Burn rates of the system Fe/KClO_4 (88/12) have been measured with pellets of various thickness in contact with various substrates using the high speed video burn rate analysis system to determine the effect of the substrate material on the measured burn rate values. No significant effect caused by the substrate was observed over a wide range of substrate materials. The substrate materials covered the range from thermal insulators to good thermal conductors, copper and aluminum metals, to quartz and MinK, an insulator, and substrate materials with low heat capacity to those with high heat capacities. This indicates that within reasonable conditions, the materials of construction in contact with these pyrotechnic heat pellets will have very little effect on the burn rate. The effect of pellet thickness was not measurable over the observed dimension range (about 0.1 to 1.25 mm thick). The effect of substrate on ease of ignition of the heat pellets was not measured, but considering the observed difficulty in ignition of some of the pellets, especially the high density pressings, any considerable heat sink may cause difficulty in ignition.

The burn rate studies (see Table 4 for a summary) described here indicate the effect of various parameters on the burn rate of pellets pressed from the pyrotechnic material Fe/KClO_4 obtained from two sources, UPI AND E-P. The parameters affecting the burn rate of pellets pressed from either

Table 4 - TEMPERATURE OF PELLET REACTION ZONE

SAMPLE #	COMPOSITION Fe/KClO ₄	DENSITY g/cc	PELLET TEMPERATURE	BURN RATE mm/s	REACTION TEMPERATURE
G5	88/12	3.5	-54	91.6	1075
			25	113.4	1137
			74	122.2	1165
			140	143.1	1234
G6	88/12	4.0	-54	89.4	1075
			26	113.4	1128
			74	120.9	1160
			142	139.8	1197
G7	88/12	5.0	-54	44.0	960
			25	53.3	1056
			74	57.5	1130
			150	87.9	
G16	84/16	2.5	-54	96.9	1203
			23	100.6	1213
			74	120.8	1221
			140	54.6	1236
G17	84/16	3.0	-54	96.9	1165
			25	102.0	1172
			74	117.8	1213
			140	128.5	1210
G18	84/16	3.3	-54	93.6	1204
			26	101.3	1193
			74	114.3	1221
			140	130.1	1220
G19	84/16	3.5	-54	87.9	1178
			26	97.5	1115
			74	112.4	1190
			140	124.7	1220
G20	84/16	4.0	-54	70.4	1172
			25	76.5	1168
			74	95.1	1203
			140	109.9	1263
G21	84/16	5.0	-54	38.5	1105
			27	43.4	1120
			74	58.5	1172
			140	67.4	1237
G22	88/12	3.0	-54	74.2	1051
			74	100.6	1140
G23	88/12	3.5	-54	78.0	1095
			25	90.1	
			74	104.8	1185
			125	118.4	1213

Table 4 - TEMPERATURE OF PELLET REACTION ZONE (continued)

G24	88/12	4.0	-54	72.2	1080
			25	85.8	1090
			74	96.4	1170
			158	120.1	1237
G26	86/14	3.5	-54	50.6	
			25	58.2	1152
			74	63.2	1133
			140	73.5	1208
G27	86/14	4.0	-54	43.6	1035
			25	49.0	1147
			74	58.0	1157
			140	66.5	1173
G29	84/16	3.5	-54	49.9	1135
			27	54.4	1123
			74	68.4	1136
			140	78.7	1145
G30	84/16	4.0	-54	42.3	1123
			28	47.1	1140
			74	54.5	1172
			140	64.6	1233
G32	88/12	3.5	-54	107.6	1077
			25	127.1	1130
			74	143.0	1160
			140	163.6	1238
G33	88/12	4.0	-54	108.2	1224
			25	126.5	1145
			74	145.8	1007
			140	172.4	1057
G34	86/14	3.0	-54	105.3	1145
			27	123.2	1007
			74	131.8	1057
			150	150.4	1118
G35	86/14	3.5	-54	109.6	1137
			26	127.3	1182
			74	136.9	1200
			140	158.4	1223
G36	86/14	4.0	-54	99.2	1161
			24	107.9	1182
			74	127.8	1196
			135	142.7	1154
G37	84/16	3.0	-54	104.9	
			25	115.2	1190
			74	128.1	
			118	139.4	

material were pressing density, Fe/KClO₄ blend ratio, and ambient temperature of the pellet and substrate at the time of ignition (not ignition temperature, which was not measured). In addition, the blends supplied by E-P were made up from iron metal powders of several particle sizes. The effect of this parameter was also used in the correlations involving the E-P blends. The burn rate correlations of these materials are best kept separate because the particle size properties of the iron in the blends supplied by the two suppliers cannot be compared.

Both plots of effects of the various studied parameters on the burn rate of these materials and equations relating the measured burn rates to the various parameters have been presented in the previous section. The parameter plots and the related equations will be useful in material development applications and in material acceptance/quality control applications for predicting burn rates of pellets of Fe/KClO₄ pyrotechnic blends. Because of uncertainty of predicted values outside of the measured range, these data should not be used outside the range of the measurements, particularly those burn rate values obtained from the fitting equations outside of the measured range. Within the range of the measurements the equations for either materials should produce satisfactory burn rate values within the reliability associated with the standard deviations presented with the parametric tables.

As seen in the results presented in the previous section, the range of parameters in the blends contained in the pressed pellets available for burn rate measurements was not wide enough to completely define the variation in burn rate with particle size and with composition. The trends appear somewhat ambiguous in a few cases. The smallest particle size iron powder was included in only the Fe/KClO₄ (88/12) blend, while the lowest particle size iron was included only in the Fe/KClO₄ (84/16) and (86/14) blends. Extending the burn rate measurements to include pellets containing blends of these materials and compositions should improve the limited understanding of burn rate variations in these regions. An improved fit should also result if these data were available.

Although the ignition temperature was not studied, the results of a DSC study are shown in Figure 40 [1]. The figure indicates that ignition is likely

to occur at around 490° C if the heating rate is high enough to overcome thermal conduction away from the ignition site.

Figure 40 - Curves of dQ/dT as a function of temperature for Fe/KClO₄ at different heating rates.

Reference

1. C. M. Love and J. E. Glaub, *DSC Investigation of the Fe + KClO₄ Reaction*, MLM-3058, Monsanto Research Corporation (May 1983), 8pp.

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