Reference Material Kydex® 100 Test Data Message for Flammability Testing

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Introduction

The Marshall Space Flight Center (MSFC) Materials and Processes Technical Information System (MAPTIS) database contains, as an engineering resource, a large amount of material test data carefully obtained and recorded over a number of years. Flammability test data obtained using Test 1 of NASA-STD-6001 (Ref. 1) is a significant component of this database. NASA-STD-6001 recommends that Kydex® 100 be used as a reference material for testing certification and for comparison between test facilities in the round-robin certification testing that occurs every 2 years. As a result of these regular activities, a large volume of test data is recorded within the MAPTIS database (Ref. 2). The activity described in this technical report was undertaken to "mine" the database, recover flammability (Test 1) Kydex® 100 data, and review the lessons learned from analysis of these data.

Kydex® 100 Characteristics

Kydex® 100 is a thermoplastic that, according to the Material Safety Data Sheet, consists of 92-94% polyvinylchloride/polyacrylic mix, 0.1-3.0% organotin compound (trade secret); 4–6 solid lubricants, stabilizers, pigments. The material is provided in sheet form. Sheets of several thicknesses have been tested. This analysis was limited to data for nominal thickness sheets (0.06 in.) to eliminate thickness as a variable.

Non-repeatable flammability behavior of Kydex® 100 has been noted previously (Ref. 3). This work identified ignition source variability, contamination of the test environment, and batch sensitivity as potential causes. The work of Reference 3 explored batch sensitivity issues and contributed significant data to the database.

The large potential variation in the organotin compound has been identified as a potential variable and is the subject of a complementary parallel investigation. In planning this work, discussions with the manufacturer revealed that, about 1990, the organotin compound was substituted as the stabilizer for the previously used compound (barium with cadmium organic compounds). Data in MAPTIS, which could have been affected by this previously unidentified change, were examined, records verified, and appropriate database changes made. All of the test data presented herein are from post-1990 samples.

The burning characteristics of Kydex® 100 are described in NASA-STD-6001's Good Laboratory Practices section describing Test 1. These data are reproduced in Table 1.

Table 1. Test 1 Data from NASA-STD-6001[1]

Material Identification	Atmosphere (% O_2)	Average Burn Length		Standard Deviation	
		(in.)	(cm)	(in.)	(cm)
Kydex® 100, 0.06-in. (0.15 cm) thickness	25.9[2]	2.7	6.9	0.3	0.8
	20.9[3]	1.7	4.3	0.1	0.25

Notes:
(1) Data are from 10 replicate tests.
(2) Pressure for 25.9-% oxygen was 14.3 psi (98.7 kPa).
(3) Pressure for 20.9-% oxygen was 14.7 psi (101.3 kPa).

Approach

Test 1 (Upward Flammability) test data found in MAPTIS for 0.6-in. thick Kydex® 100 were downloaded and entered into an EXCEL™ workbook for analysis. Some of the paper files for the tests were reviewed for details not currently recorded in the MAPTIS system. Videotapes were secured from the Materials Combustion Research Facility (MCRF) files, and most were reviewed at least twice. Event timing data and observations were made from the film and recorded in EXCEL™ workbook format for analysis.

Data Review and Analysis

The Kydex® 100 burn length data recorded for standard Test 1 conditions were plotted as a function of oxygen concentration (Figure 1). Data from individual runs were used, rather that the average of data sets or groups. The data produce a pattern that indicates the burn length data forms two groups of data, which become increasingly separated as the oxygen concentration increases. This separation into two groups is the primary focus of the remainder of this study and shows that the data in the lower set agrees with the data expectation from NASA-STD-6001 (Table 1) for the higher oxygen concentration (25.9%). The expected data range from NASA-STD-6001 for 20.9-% oxygen is somewhat lower than the data.

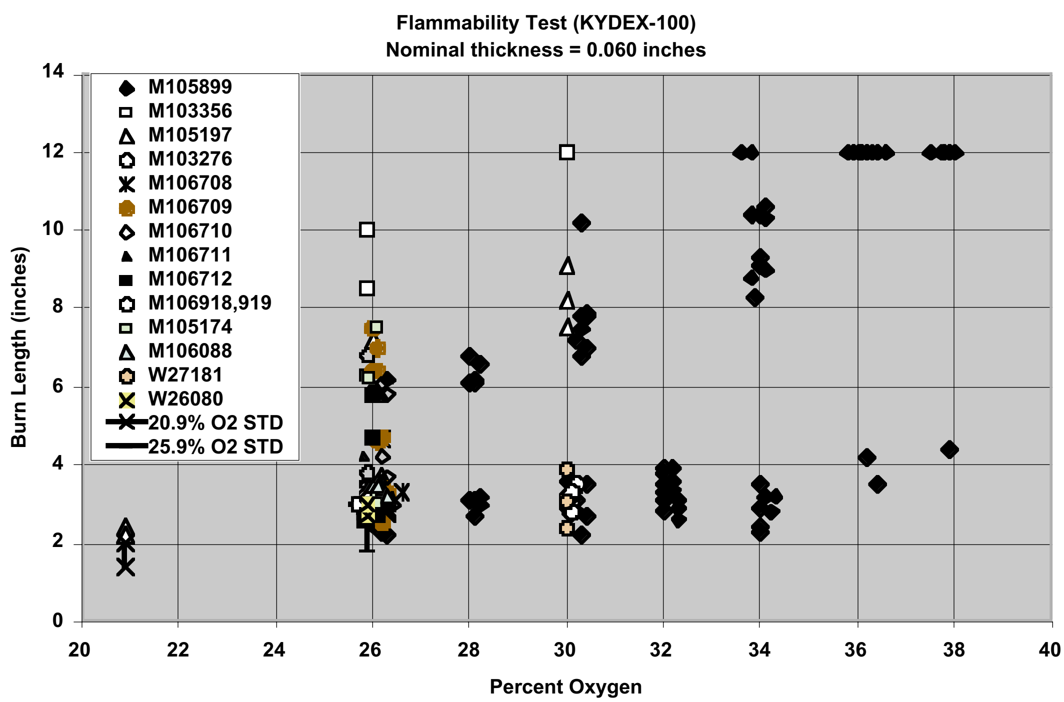

Figure 1. Kydex® 100 Burn Length Data

The Kydex® 100 data are for a variety of total pressures. The burn length data clearly shows the two groupings and that data from the same test are in both groupings. Since the burn length is used as a pass or fail criterion, the data were divided into burn length above and below 6.0 in. The resulting data are shown in Figure 2.

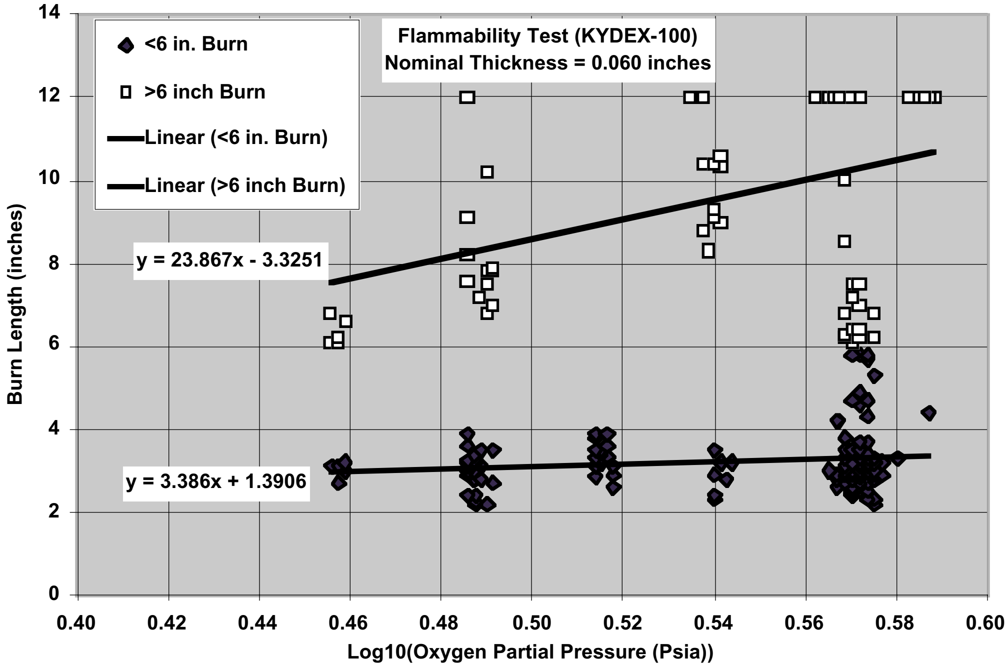

Figure 2. Burn Length Segregated Kydex® 100 Data

By segregating the burn length data into two groups, fit-comparisons of the data were produced. The linear data fit-comparisons show a dramatic difference in the two data sets. Note that data comparable to the standard exist in the lower burn length set and the upper set across the whole range of oxygen concentrations.

In Test 1, the burn rate and burn length for each sample are recorded. The burn rates corresponding to the two groups of burn lengths are plotted in Figure 3. Note that some of the burn rate data for burn lengths greater than 6 in. groups with the burn rate data for burn lengths less than 6 in.

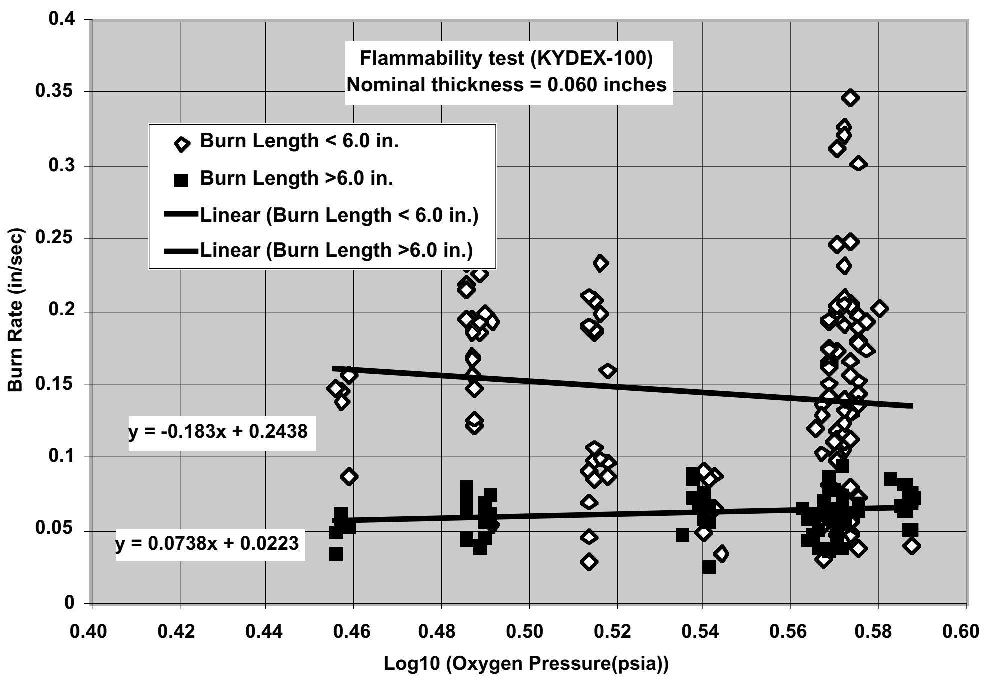

Figure 3. Kydex® 100 Burn Rate Data as a Function of Oxygen Partial Pressure

This effect can be more clearly seen in Figure 4, in which burn length is plotted against burn rate. The test number identifies the data, and no segregation was made by burn length. Data for burn rates above 0.1 in./sec all agree with the 25.9-% oxygen criterion from NASA-STD-6001. When the burning rate is lower, the burning length tends to increase. Many of the tests plotted are from Reference 3, in which each test number corresponded to a different batch of 10 tested samples of Kydex® 100. Note that data from several of the test numbers exist in both the constant-burn-length range and the burn-rate-independent region. This tends to indicate that batch properties did not change the burning characteristics.

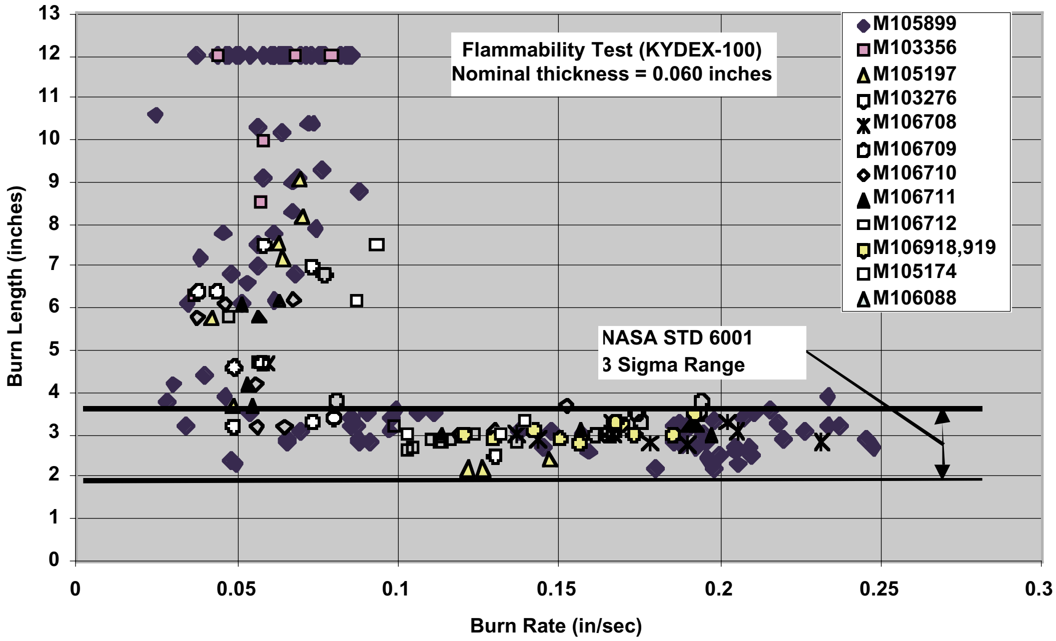

Figure 4. Burn Length versus Burn Rate Data

The batch-sensitivity study data are further examined in Figure 5, in which burn length is plotted against sample number. Sample number usually corresponds to run sequence number. Note the appearance of the two groups of low and high burn rates. The occurrence of a low or high burn length appears to be random, and all batches exhibit this characteristic.

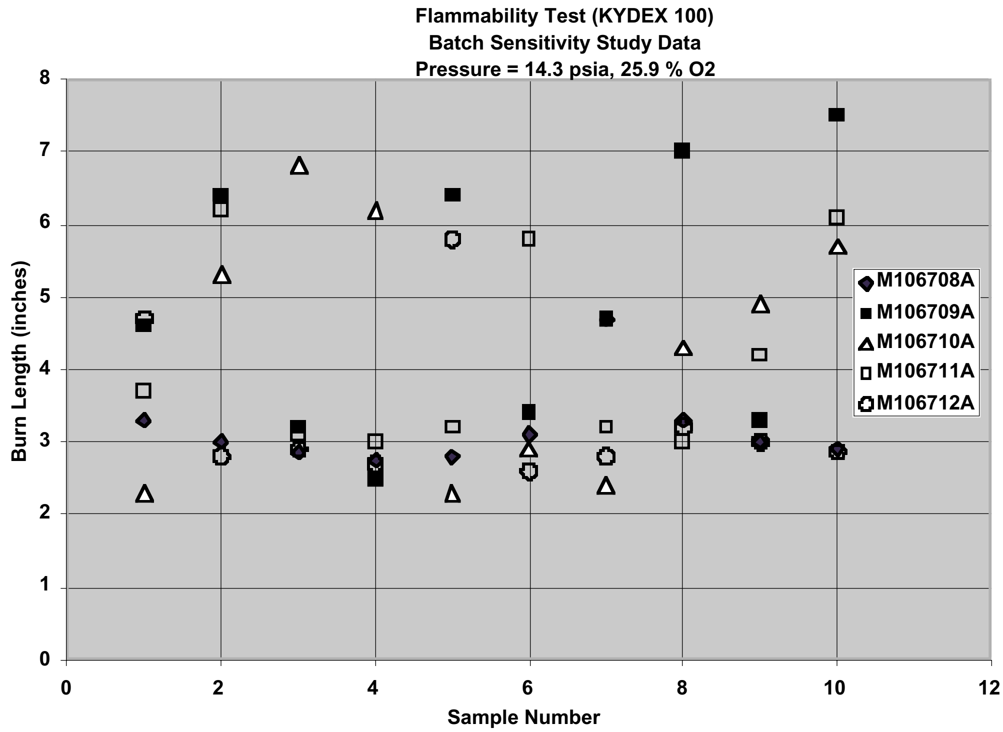

Figure 5. Burn Length versus Sample Number

Sufficient data are available at the seven oxygen concentrations (from 26 to 38% in 2-% increments) to determine the sample frequency for a given burning length. The sample frequency provides a measure of the percent of time a given burn length will be obtained. Data from 93 specimens tested in 25.9- to 26-% oxygen were grouped to determine the burn length sample frequency for one test condition. These data are shown in Figure 6. A sparse data sample of 10 samples is available for 28-% oxygen (Figure 7).

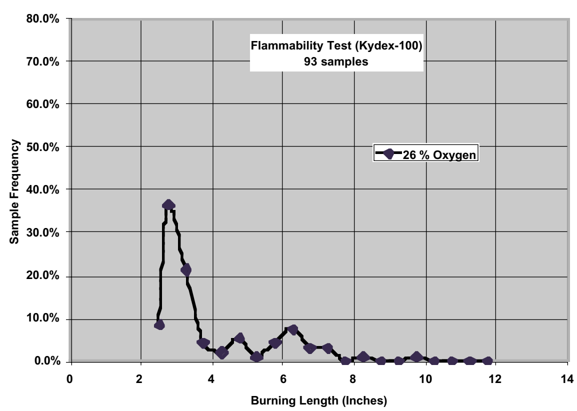

Figure 6. Sample Frequency versus Burn Length at 26% Oxygen

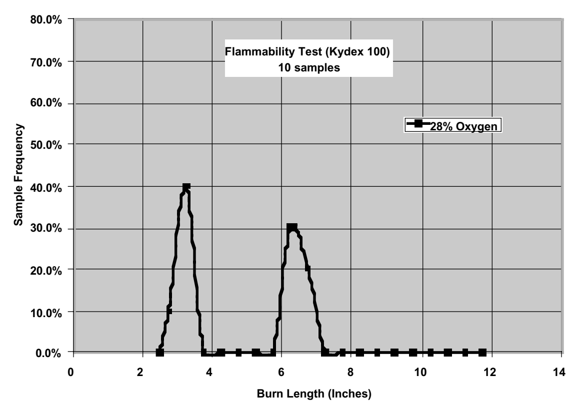

Figure 7. Sample Frequency versus Burn Length at 28% Oxygen

Data from 34 specimens tested in 30-% oxygen were grouped to determine the burn length sample frequency at another test condition. These data are shown in Figure 8. Note that three peaks appear. A substantial number of the samples exhibit burning lengths below 6.0 in. Another group partially sustains burning and burns in the 6- to 8-in. range. A group of 8.8% exhibits total burns.

Similar plots are provided for 32-, 34-, 36-, and 38-% oxygen (Figures 9 to 12, respectively). These plots show the two groups discussed throughout this section. The first group clusters about a burn length of approximately 2.7 in. This is interpreted as the burn length realized from the application of the energy from the igniter. Without the igniter energy application, a certain percent of the samples will not have enough energy to sustain burning and will extinguish shortly after the igniter stops burning. Another percentage will have sufficient energy to continue burning and then self extinguish or continue burning until the fuel is consumed. The higher oxygen concentration environment produces a more rapid production of combustion energy; thus, the higher burning lengths are observed, and propagation from extinguishment to sustained burning occurs more frequently.

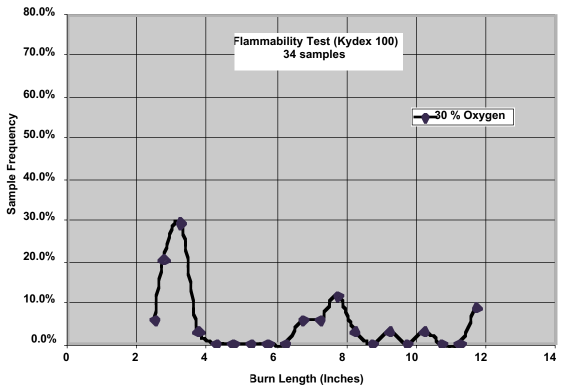

Figure 8. Sample Frequency versus Burn Length at 30% Oxygen

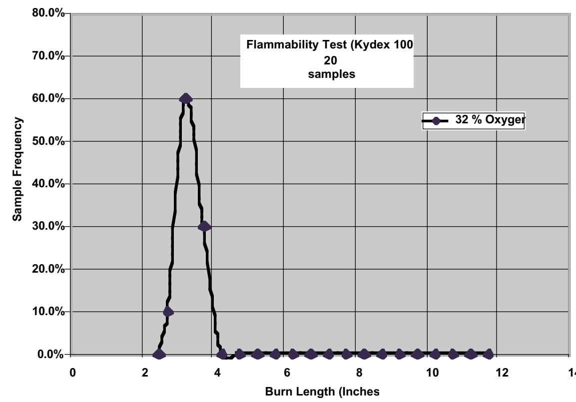

Figure 9. Sample Frequency versus Burn Length at 32% Oxygen

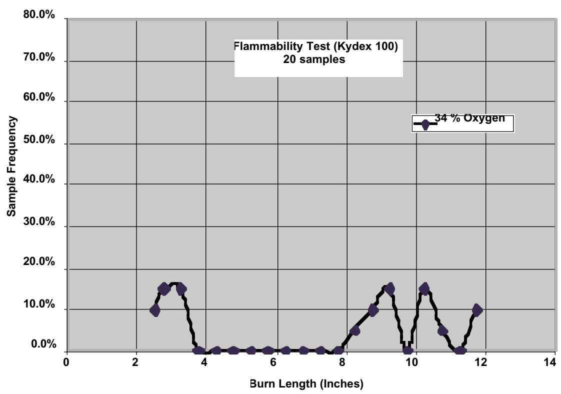

Figure 10. Sample Frequency versus Burn Length at 34% Oxygen

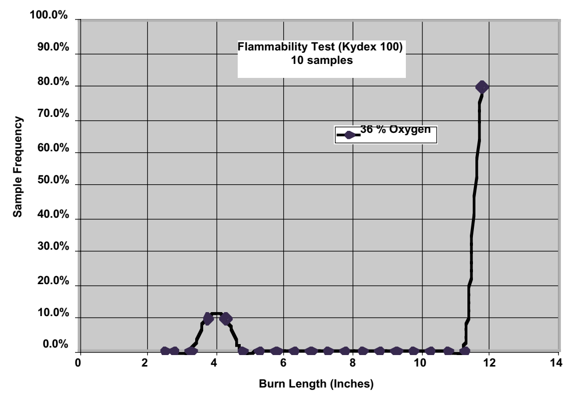

Figure 11. Sample Frequency versus Burn Length at 36% Oxygen

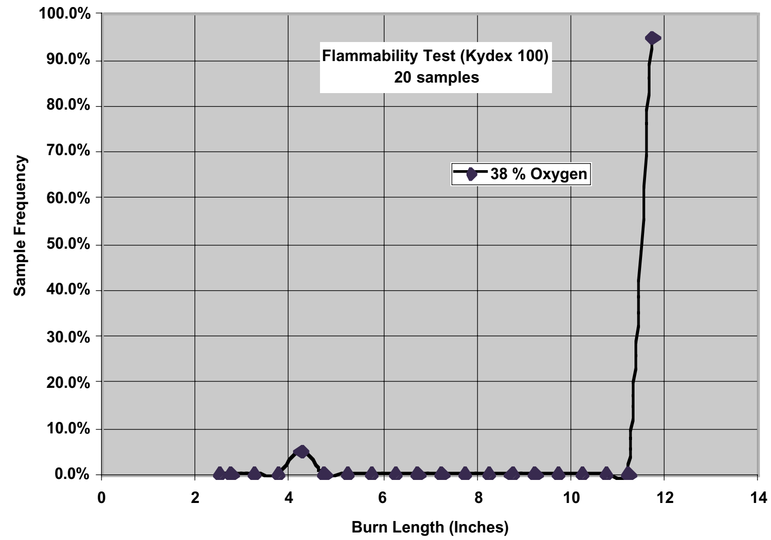

Figure 12. Sample Frequency versus Burn Length at 38% Oxygen

The integral of the sample frequency (the cumulative distribution) is provided in Figure 13. The distribution shows that at 25.9-% oxygen, 84% of the samples tested will not burn more than 6.0 in.; but 14% of the samples will burn more than 6.0 in. Also, note that none of the samples produced sustained burning by consuming all 12 in. of the sample. At the higher oxygen concentration of 30%, 42% of the samples will not burn 6.0 in.; accordingly, 58% will burn more than 6.0 in.

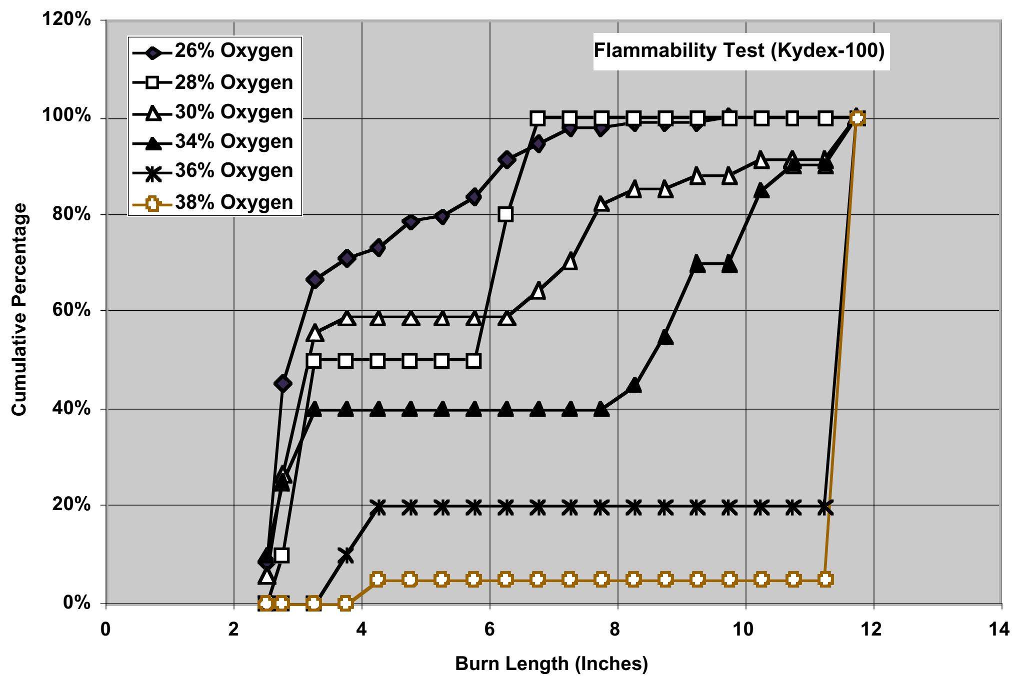

Figure 13. Kydex® 100 Burning Length Cumulative Percentage Distributions

A clearer understanding of the burning length probability can be seen by plotting the burning length frequency for burning lengths above 6.0 in., using the data in Figure 13. These data are shown in Figure 14, in which the burning frequency shows a near linear increase with oxygen concentration. An exception is at 32-% oxygen, where 20 samples were tested and none burned 6.0 in. or more.

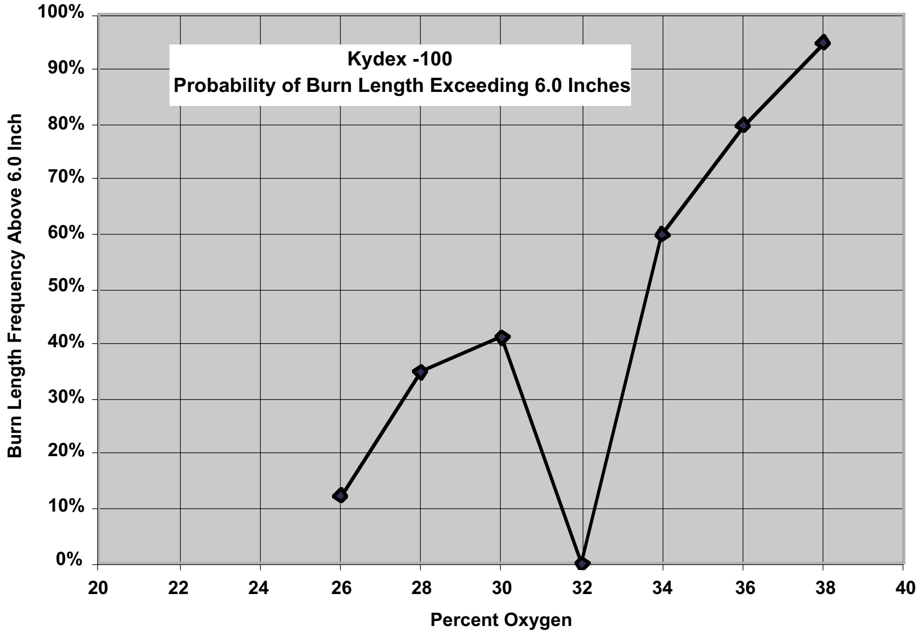

Figure 14. Probability of Kydex® 100 Burn Lengths above 6.0 in.

The data in Figures 13 and 14 challenge the prevailing concept of oxygen level thresholding. If sufficient samples are tested, some burn lengths above 6.0 in. will occur for all oxygen concentrations above 26-% oxygen, and the frequency of burn length above 6.0 in. increases with oxygen level. Of those samples that burn more than 6.0 in., only a few have the independent energy production to sustain burning up to 12.0 in. This implies that the material will extinguish itself.

Figure 15 shows the percent of samples tested that had a total burn versus oxygen concentration level. In these cases, sufficient energy was released to sustain continuous burning well after the igniter was out. The character of these data versus oxygen concentration appears to fit the oxygen thresholding concept.

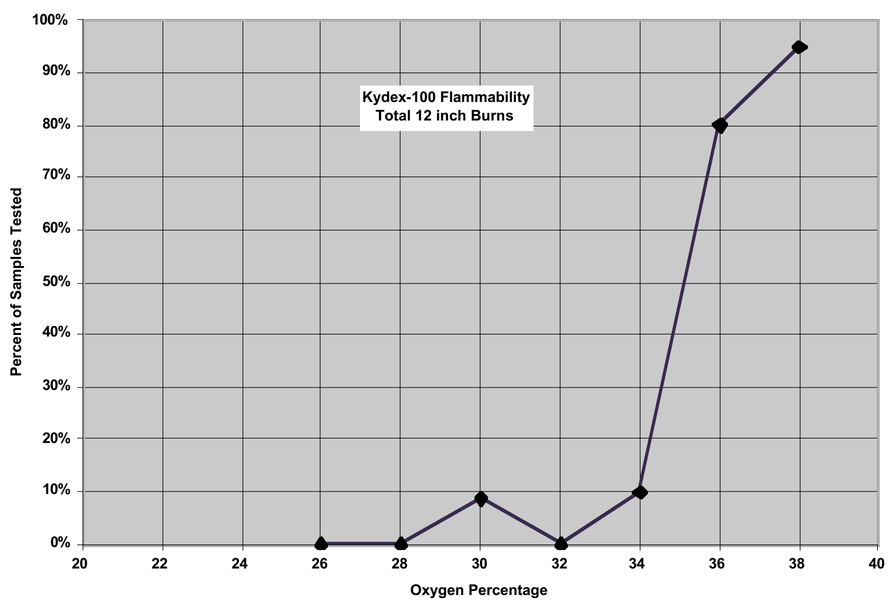

Figure 15. Probability of Kydex® 100 Burn Lengths of at least 12 in.

Probability and Sample Number Discussion

The concern for providing an accurate characterization of material flammability has persisted over the years of testing and data sampling. Reference 4 highlights the key role of the number of samples tested in establishing the error associated with the samples tested for promoted combustion testing (Test 17). Reference 4 provides the formula (from Reference 5) for the maximum error of estimate for a given confidence level.

$E = Z_{\alpha/2} /(2n^{1/4})$ percent error
n = number of test specimens
$Z_{\alpha/2}$ = normal distribution factor

where $Z_{\alpha/2} = 1.96$ for $\alpha = 0.050$
$Z_{\alpha/2} = 2.576$ for $\alpha = 0.010$

This formula yields the following values:

Test Error Estimate

Zalp/2 =	1.96	2.576
no of test	95% conifidence	99% conifidence
3	57%	74%
5	44%	58%
10	31%	41%
16	25%	32%
40	15%	20%
100	10%	13%

The practice of using a small sample size leads to a very large uncertainty in the data obtained; moreover, the foregoing analysis assumes the data are at least near a normal distribution. As shown in the preceding section, the material Kydex® 100 may form threes subset distributions within the total distribution of flammability burn lengths. This confounds the ability to determine accurately the number of samples needed to minimize the error in each of the three subsets of distributions to a quantifiable level.

Conclusions

Based on the substantial test data obtained over the years, several conclusions can be drawn for the flammability characteristics of Kydex® 100.

1. Kydex® 100 flammability characteristics do not agree with the NASA-STD-6001 stated burning length range.
2. The burning length range stated in NASA-STD-6001 appears to be produced by igniter-on conditions and does not represent the material’s burning characteristic once ignited but without the ignition source energy input.
3. No batch burning characteristics were identified, but batch effects on the probability of different burn length classes were not specifically eliminated.
4. The concept that there is a single oxygen level that defines whether a sample will burn less or greater than 6.0 in. is seen to be quite inadequate.
5. Sufficient testing can establish material characteristics probability curves to provide the engineer with the probability that the material will sustain a burn length of at least 6.0 in. or will sustain burning until all material is consumed. A simple pass/fail criterion may not be possible or practical. Future application of flammability data for some material classes may require the design engineer to assess the risk based on the probability of an occurrence and the probable outcome with different materials as characterized with cumulative burn length distribution for specific use conditions.
6. Flammability data for other materials and other classes of materials should be examined to determine if similar probabilistic burning characteristics are found. The similarity between the upward flammability and promoted combustion tests, along with the apparent uncertainty in determining a unique threshold pressure for metals, suggests that the data should be reexamined to determine if a probability distribution curve versus pressure level is established by the data.

7. Based on the current work, the minimum number of samples recommended for standard Test 1 testing is 10 for each test condition. Evaluation of Test 1 data for other materials may suggest this number be increased.

Acknowledgements

Flammability test data were obtained through access to the MAPTIS database. The review and discussions of the analysis approach and data results by Bob Jacobs materially contributed to the understanding of flammability testing. His assistance is greatly appreciated.

References

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