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Agreement No. FA67NF-AP-24

Project No. 520-005-01X

CRASH FIRE HAZARD RATING SYSTEM FOR CONTROLLED FLAMMABILITY FUELS

MARCH 1969

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Bureau of Mines

Pittsburgh, Pennsylvania 15213

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CRASH FIRE HAZARD RATING SYSTEM FOR CONTROLLED FLAMMABILITY FUELS

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Pittsburgh, Pennsylvania

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FOREWORD

This report was prepared by the Bureau of Mines for the Federal Aviation Administration. The work effort was part of a program of the Engineering and Safety Division, Aircraft Development Service, Washington, D. C. The work was administered under the direction of Mr. Ralph A. Russell who served as project engineer for the Propulsion Section, Aircraft Branch, Test and Evaluation Division, National Aviation Facilities Experimental Center, Atlantic City, New Jersey.

ABSTRACT

A method for rating the potential crash fire hazard of gelled and emulsified hydrocarbon fuels was developed at the request of the Federal Aviation Administration since the use of thickened aircraft fuels may provide a significant reduction in the crash fire hazard. The rating system is designed primarily for screening candidate thickened fuels with respect to their overall flammability hazard under laboratory-scale conditions. The fuel properties included in the rating system are minimum autoignition temperature, flash point, volatility rate, self spread rate, regression or burning rate, flame spread rate, and fire ball size under impact conditions; methods for determining these fuel properties are also described in the report. Experimental data on such fuel properties are presented for JP-4 and JP-5 or Jet A thickened fuels that were formulated with an emulsifying agent or with one of three different gelling agents submitted for evaluation. The results of these determinations and the numerical ratings derived for each fuel composition are discussed.

TABLE OF CONTENTS

	Page
ABSTRACT	v
INTRODUCTION	1
FUEL PROPERTIES IN PROPOSED RATING SYSTEM	1
1. Minimum Temperature for Hot Surface Ignition	2
2. Minimum Temperature for Formation of Flammable Mixtures	2
3. Relative Volatility Rate or Time for Formation of Flammable Mixtures	2
4. Relative Self-Spread Rate	3
5. Regression or Burning Rate of Bulk Fuel	3
6. Horizontal Flame Spread Rate Under Static Conditions	5
7. Fire-Ball Size or Radiation Intensity Under Impact Conditions	5
PROPOSED CRASH FIRE HAZARD RATING SYSTEM	9
CONCLUSIONS	16
RECOMMENDATIONS	16
REFERENCES	17
APPENDIX	1-1

LIST OF ILLUSTRATIONS

FIGURE

1. Vapor pressure versus time obtained for 3 fuels in the modified Reid Vapor Pressure Apparatus 4

2. Selected frames from motion picture films of fire developed in "Fuel Drop Fire Tests" with 5 lbs of liquid fuel at a drop height of 20 feet 6

3. Selected frames from motion picture films of fire developed in "Fuel Drop Fire Tests" with 5 lbs of thickened fuel at a drop height of 20 feet 7

4. Thermal radiation vs time obtained for 3 fuels in "Fuel Drop Fire Tests" (Thermopile at distance of 30 feet). . 8

LIST OF TABLES

TABLE		Page
1.	Proposed crash fire hazard rating system	10
2.	Summary of experimental data for JP-4 liquid fuel and various JP-4 thickened fuels	11
3.	Summary of experimental data for Jet A liquid fuel and various Jet A or JP-5 thickened fuels	12
4.	Comparison of various fuels according to the proposed fire hazard rating system	13
5.	Comparison of thermal radiation data from fuel drop fire experiments with various fuels	15

CRASH-FIRE HAZARD RATING SYSTEM FOR CONTROLLED FLAMMABILITY FUELS

INTRODUCTION

Many fatalities that have occurred in aircraft crashes during take-off or landing have been attributed to the fire and smoke produced following ignition of fuel dispersed from ruptured fuel tanks. In an effort to reduce the crash fire hazard, the Federal Aviation Administration sponsored a research program in 1964 to determine the feasibility of using thickened fuels in aircraft. Results of this program (Refs 1 and 2) indicated that the potential fire or flammability hazard is greatly reduced for aircraft fuels containing 1.5 weight percent of CHBA gelling agent or N-"coco"-γ-hydroxybutyramide (Ref 3). Although these results were obtained under small-scale simulated crash conditions, similar results were found by the Federal Aviation Administration under full-scale simulated conditions (Ref 4). Other work (Refs 5, 6, and 7), particularly that sponsored by the Army, has led to the development of fuel emulsions that also appear promising as "controlled flammability fuels" for aircraft. In the present work the Bureau of Mines was requested by the FAA to develop a method of rating the potential crash fire hazard of gelled and emulsified fuels. The rating system described in this report is applicable primarily to hydrocarbon-type aircraft fuels. Test methods for determining the fuel properties used in the rating system are described in the appendix.

FUEL PROPERTIES IN PROPOSED RATING SYSTEM

To evaluate the potential fire hazard associated with aircraft fuels, their ignitability and flammability properties must be considered under the anticipated use conditions. In a survivable aircraft crash situation, the initial and most serious hazard following impact is fuel spillage and ignition of the fuel vapors by a heated surface or other initiating source. The flash propagation that can occur under such conditions would greatly reduce the chance of survival. Thus, to minimize the crash fire hazard, an improved fuel should provide a significant reduction in the extent of fuel spillage and the formation of flammable vapor-air mixtures. The rate at which the fuel vapors form and the rate at which the fire spreads are particularly important in this connection. Generally, the possibility of escaping from an aircraft fire is highly remote after a few minutes, at most; the determining factors include the rate of fire growth as well as the size or intensity of the fire. These and other related factors were considered in selecting the various fuel properties for the proposed crash fire rating of thickened hydrocarbon aircraft fuels.

The base fuels used in this work were JP-4, Jet A, and JP-5. The gelled compositions of these base fuels were formulated with one of the following additives: 1-1/2% gel A (CHBA), 3% gel B and 6.9% gel C. One aqueous emulsified fuel (D) containing approximately 2% additive was also

examined. Since the emulsified fuel and the gelled B fuels were prepared by the suppliers, their base fuel composition was not necessarily the same as that which was used in preparing the other thickened fuels.

1. Minimum Temperature for Hot Surface Ignition

The ignitability characteristics of fuels are defined in part by the minimum ignition temperatures and minimum spark ignition energies of their fuel vapors in air. Since there is little variation in the minimum ignition energies of most aircraft hydrocarbon fuels (optimum fuel vapor-air mixtures), they are not included in the rating system. The heated vessel method (Ref 8) for determining minimum autoignition temperatures (AIT's) was selected because this method usually gives the lowest possible value when the fuel vapors are in contact with a heated surface. The hot manifold test was rejected because it normally gives poor reproducibility and does not reflect the maximum ignition hazard except, possibly, in those instances when the fuel vapors are trapped in confined spaces around the manifold. Minimum AIT's depend greatly upon the heat of combustion and chemical reactivity of the fuel and can vary with fuel-air ratio, fuel injection velocity, vessel size, and the fuel contact time or heating time. The AIT's of the JP-4 thickened fuels examined here were not sensitive to a variation of injection velocity between 0 and 60 ft/sec (41 miles/hr). Since ignition occurs in the vapor state, the minimum AIT's of the thickened fuels will not differ significantly from those for their liquid base fuels, providing the concentration of thickening agent is small (<5%).

2. Minimum Temperature for Formation of Flammable Mixtures

One measure of the flammability hazard is the flash point or minimum temperature required for a combustible liquid or solid to form flammable vapor concentrations (lower limit) in air. The Cleveland Open Cup Method (Ref 9) is not satisfactory for thickened fuels because of the possible air convection and condensation effects and because the sample temperature is not uniform at the recommended heating rate (10°F/min). The Tag Closed Cup Method (Ref 10) is more suitable, although even with this tester a lower heating rate than the recommended 2°F/min appears necessary because of the low thermal conductivity of the thickened fuels. As a comparison, the JP-4 gel A has a flash point of approximately 40°F by the Cleveland Open Cup and 10°F by the Tag Closed Cup. Flash points are related primarily to the volatility or vapor pressure of the chemical constituents in the fuel; thus, they should vary little for thickened fuels having the same base fuel if sufficient time elapses for near equilibrium vapor pressures to exist. A thickening agent whose flash point is not lower than that of the base fuel is assumed.

3. Relative Volatility Rate or Time for Formation of Flammable Mixtures

Because of the great importance of time in an aircraft crash situation, a relative measure of the time at which flammable fuel vapor-air mixtures

may form is included in the rating system. A modified ASTM Reid Vapor Pressure Test Method (Ref 11) was used for this purpose. The time required for the fuel to attain a vapor pressure of 1/2 psig at 100°F was selected, since the corresponding fuel concentration in air will fall well within the flammable range for the fuels of interest. In our modified procedure, the fuel is under quiescent conditions. The increased vapor or mist formation encountered under impact conditions is reflected in the "Fuel Drop Fire Test" (Item 7). The rate of vapor formation depends primarily upon the viscosity and surface tension of the particular fuel; the exposed surface area of the sample is also important but this is held constant in the above determination. Figure 1 shows the great difference between the vapor pressure data obtained for the JP-4 liquid fuel and two of the JP-4 thickened fuels as a function of time. At final equilibrium conditions, the vapor pressures of the thickened fuels can be expected to be the same as or comparable to that of the JP-4 liquid; such conditions exist within the fuel tank of an aircraft.

4. Relative Self-Spread Rate

The reduced spillage that can occur with thickened fuels is reflected partly in the proposed "Slope Test" (2° slope). In this test, a linear rate of fuel spread is measured after a small quantity of fuel is ignited and permitted to spread. The self-spread rate depends primarily upon the viscosity of the fuel when the fuel temperature is uniform. With a flame present, the fuel temperature is not uniform and the self-spread rate also depends upon the thermal conductivity and "softening" characteristics of the fuel. The importance of using a heat source here is emphasized by the fact that some of the thickened fuels break down at relatively low temperatures; the gel A fuels are an example as they tend to soften at approximately 125°F. The effect that high shear forces may have upon the fuel spillage and flammability hazard is included in the impact tests under Item 7.

5. Regression or Burning Rate of Bulk Fuel

The heat intensity of a fire is determined in part by the rate at which the fuel is consumed by burning. Here, 8-inch diameter trays were used to determine the linear regression rates of burning of the liquid and solid fuels, although larger trays are usually required to minimize the effect of heat conduction losses; trays at least 2 feet in diameter are required to obtain the maximum burning rates for many fuels (Ref 12). The burning rates of fuels will vary directly with their heats of combustion and inversely with their heats of vaporization. The rates for most liquid hydrocarbon fuels do not differ greatly; also, their rates should not differ greatly with the addition of small concentrations of most thickening agents.

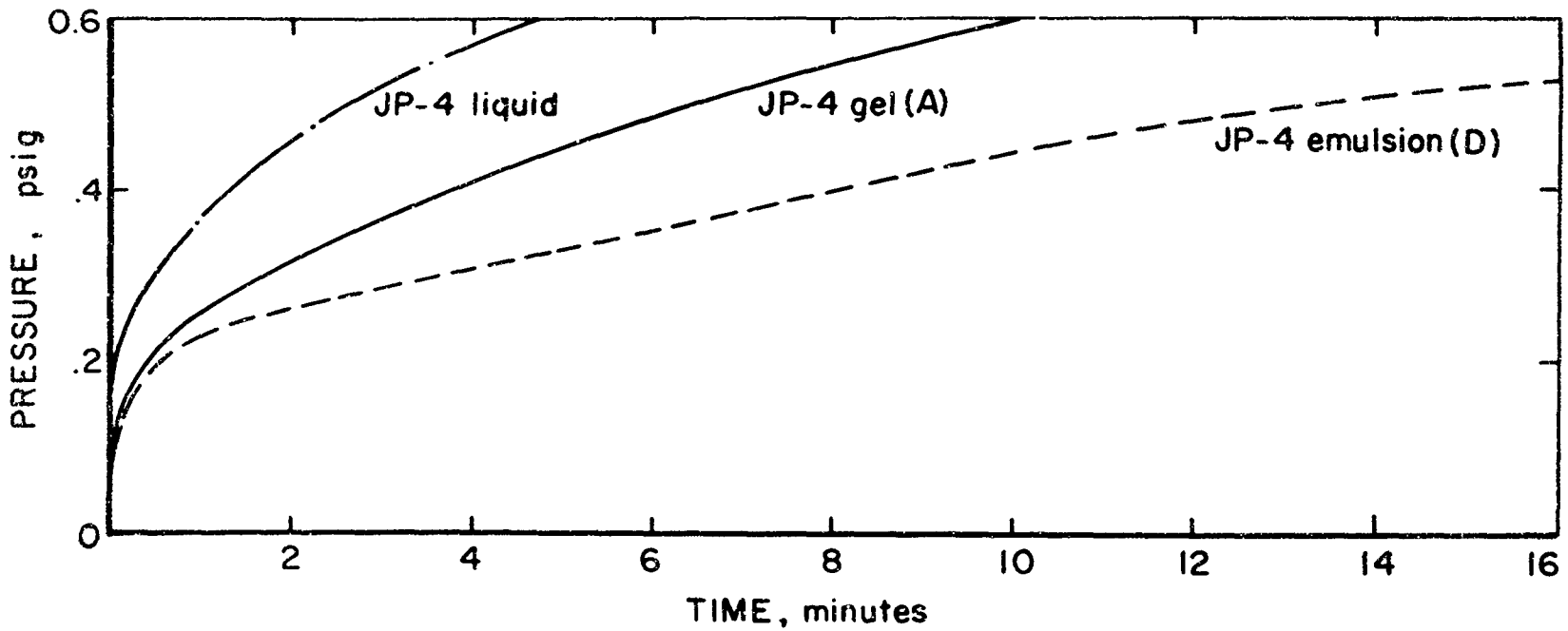


Figure 1. - Vapor pressure versus time obtained for 3 fuels in the modified Reid Vapor Pressure Apparatus.

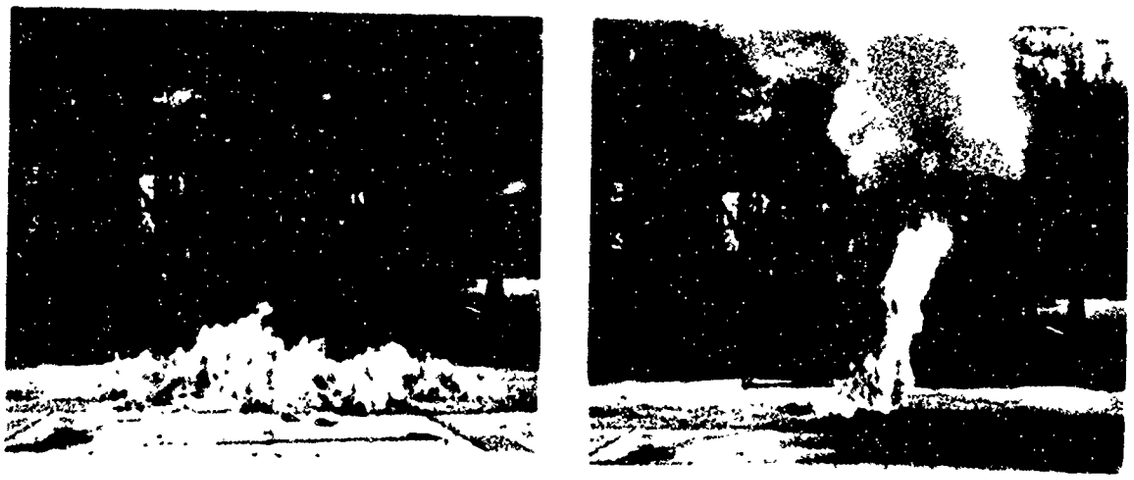
6. Horizontal Flame Spread Rate Under Static Conditions

The flame spread rate under static conditions reflects the flash propagation hazard associated with the fuel at rest; this condition is encountered in a crash where ignition of the vapors from spilled fuel is delayed. In this work, the rate of flame travel was determined near the surface of fuel ignited in a 3-inch angle trough; with smaller size troughs, the rates tended to be lower, particularly for the thickened fuels. Initially, the fuels were compared using half-filled and completely filled troughs. However, variations observed in the rates by the two methods were later found to be attributed largely to differences in sample preparation. Since flame speeds do not vary greatly for the optimum vapor-air mixtures of many hydrocarbon fuels, differences between the flame spread rates of thickened and unthickened fuels will depend primarily upon their thermal conductivity and volatility properties.

7. Fire-Ball Size or Radiation Intensity Under Impact Conditions

The most important item in the proposed rating system is comparison of the flammability hazard for the fuels under impact conditions. Because of the turbulence and rapid formation of flammable vapor-air mixtures or mists possible under such conditions, the rates of flame spread are greater than observed under quiescent conditions. Particularly important is the size of fire ball that may develop immediately following ignition (flash propagation) and during the subsequent burning of spilled fuel. Such information was obtained in small-scale "Fuel Drop Fire Tests" in which 5 pounds of fuel was dropped from a height of 20 feet and the maximum fire-ball size attained within 1 and 10 seconds was measured. The photographs in figures 2 and 3 show some of the results obtained with the JP-4 and Jet A thickened and unthickened fuels. As noted, the size of the fire ball at 1/2 second after ignition is greatest with the JP-4 liquid; also the extent of such flash propagation is noticeably greater with the emulsified JP-4 fuel (D) than with the gelled (A) JP-4 or Jet A fuels. The Jet A gelled fuel gave the most favorable results. Generally, the maximum fire-ball size was reached before 10 seconds with the JP-4 liquid and JP-4 emulsified fuel. Such factors as the fuel spray pattern, wind, and temperature will influence the symmetry as well as the size of the fire ball.

Since the fire ball in these experiments is not symmetrical, thermal radiation measurements were also made to compare the fire hazard of the fuels under impact conditions. The measurements were made with thermopiles located 30 feet from the point of impact and ignition. Figure 4 shows the variation of the radiation intensity (milliwatts/cm^2) with time that was obtained in one set of experiments with the JP-4 liquid and two thickened fuels. These results are consistent with the corresponding fire-ball size measurements in that the radiation or the fire-ball size immediately following ignition is greatest with the JP-4 liquid and least



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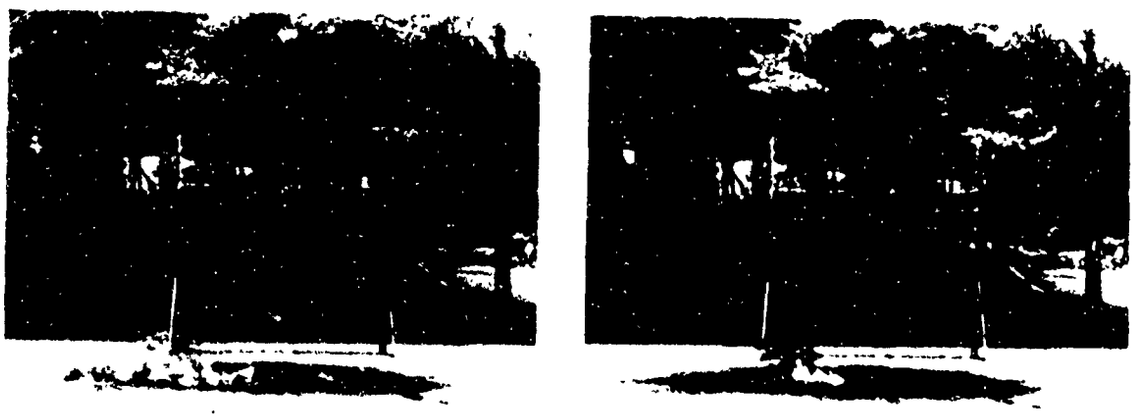
JP-4 Liquid



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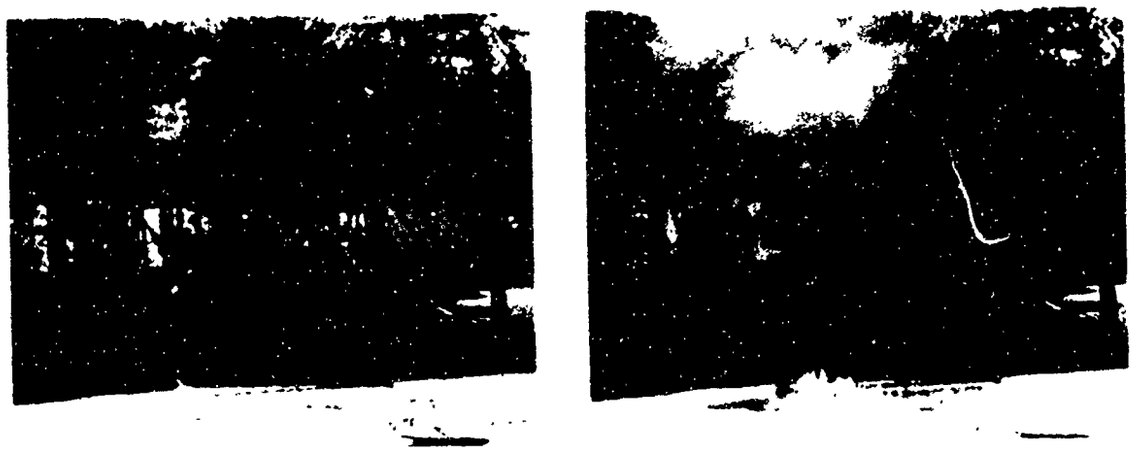
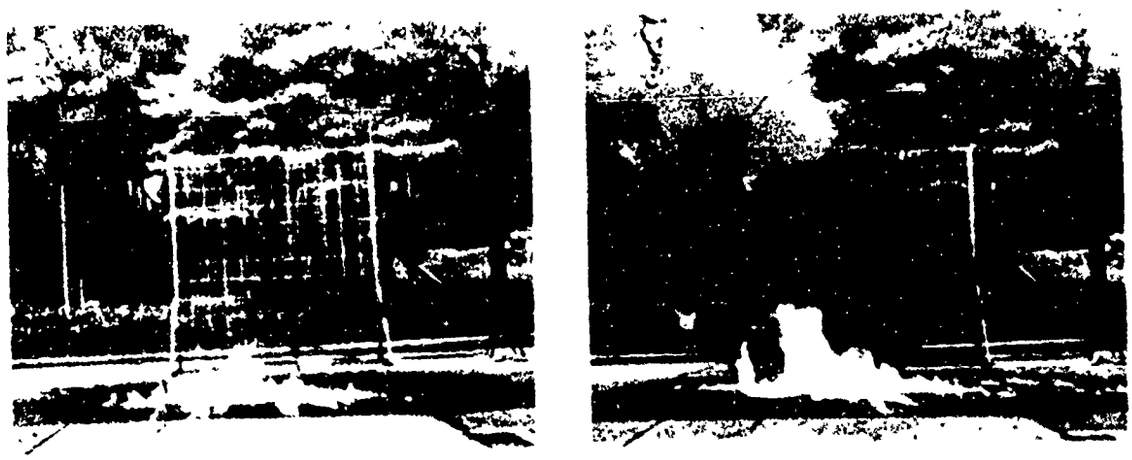
Jet A Liquid

Figure 2. - Selected frames from motion picture films of fire developed in "Fuel Drop Fire Tests" with 5 lbs of liquid fuel at a drop height of 20 feet.



1/2 sec 10 sec

JP-4 Gel (A)



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JP-4 Emulsion (D)

Figure 3. - Selected frames from motion picture films of fire developed in "Fuel Drop Fire Tests" with 5 lbs of thickened fuel at a drop height of 20 feet.

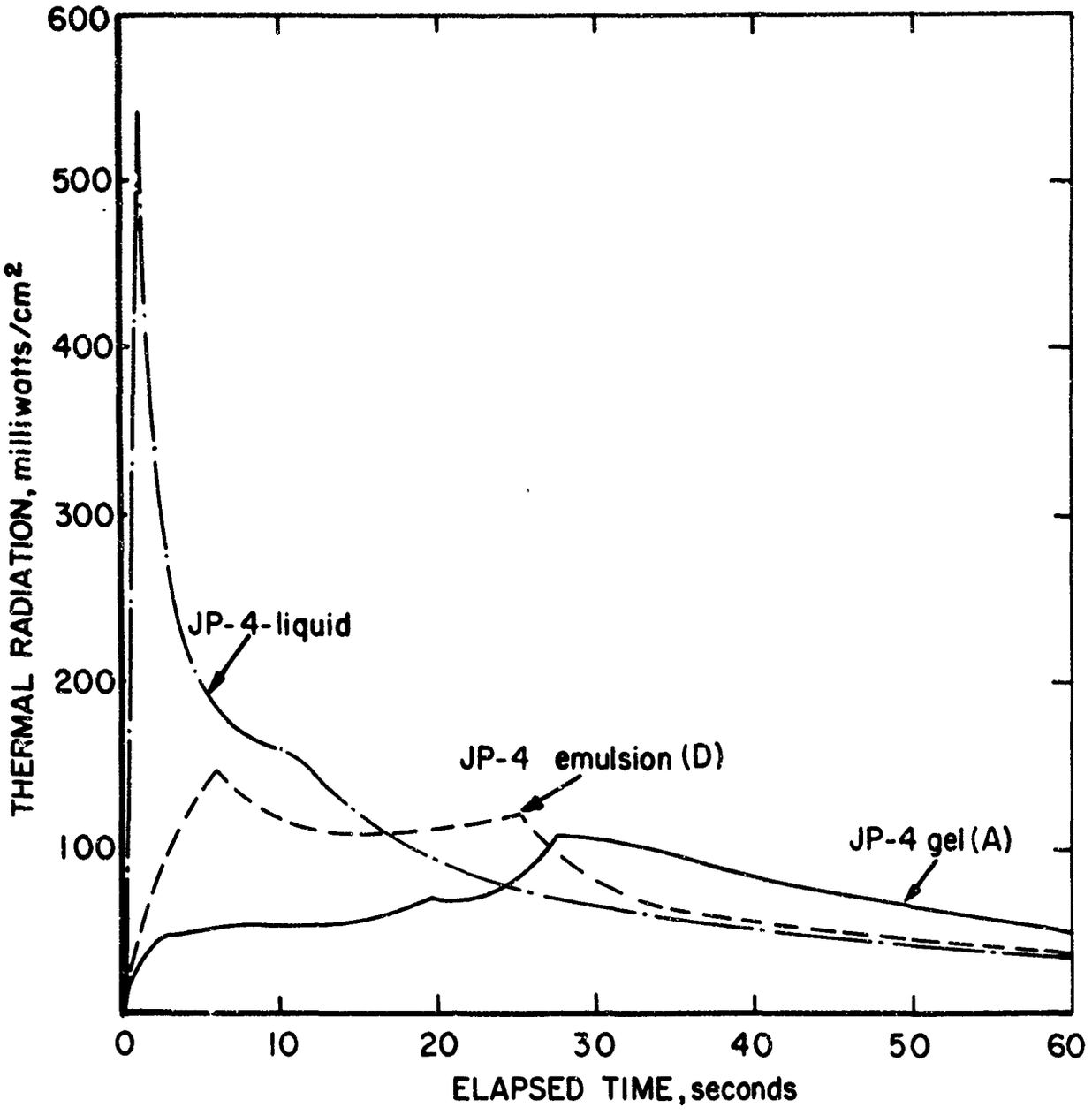

Figure 4. - Thermal radiation vs time obtained for 3 fuels in "Fuel Drop Fire Tests" (Thermopile at distance of 30 feet).

with the JP-4 gelled fuel (A); also, the peak in the radiation curve for the JP-4 emulsified fuel (D) occurs much earlier than for the JP-4 gelled fuel. Although the radiation measurements are suitable for comparing the level of fire intensity, they provide only qualitative information on the distance over which the fire has spread.

PROPOSED CRASH FIRE HAZARD RATING SYSTEM

Initially, a rating system was devised for use with a single base fuel such as JP-4. Since thickened fuels with various hydrocarbon base compositions are of interest, the rating equations were changed to provide a broader base for comparison. Also, the relative volatility rate under dynamic conditions and the flame spread rate in partially filled fuel troughs were omitted for the reasons cited in the previous section of this report. The proposed rating system is outlined in table 1.

In deriving the equations, primary consideration was given to the importance of the particular property in defining the potential crash fire hazard. Furthermore, the reference base value for each equation was selected to give a zero or low rating for the JP-4 liquid fuel. As noted in table 1, fuels which have a flash point of 0°F or less are rated zero on this item and those with a flash point of 200°F or more receive a maximum rating of 10; some new candidate jet fuels have flash points close to 200°F. A maximum possible rating of 10 is assigned to each item except for the self-spread rate and the fire-ball size under impact conditions. The latter items are rated higher because of their greater importance in assessing the crash fire hazard associated with fuel spillage. A maximum overall rating of 95 is possible for the fuel with the most desirable properties under the proposed scheme.

Tables 2 and 3 summarize the experimental data obtained for the JP-4 and JP-5 or Jet A thickened fuels; corresponding data for the base fuels are also included. Average values and their reproducibility are given where more than one trial was made to define a fuel property. The vapor pressure and flame spread rate data (Items 3 and 6) for the JP-4 emulsified fuel displayed the greatest scatter. Generally, the minimum AIT's and regression rates varied little for all the fuels, whereas the other fuel properties for most of the materials varied noticeably, depending upon the base fuel or thickening agent composition. It is also important to note that the flash point of 108°F for the JP-5 gelled fuel (B) is low compared to that expected for a JP-5 based fuel (~140°F); the composition of the JP-5 fuel that was used by the vendor of the gelled material is not known.

A comparison of the potential crash fire hazard of the fuels is made in table 4 according to the proposed rating system; the data in tables 2 and 3 were used to compute the various ratings. As noted, the Jet A fuel rates noticeably higher than JP-4 on the basis of this rating scheme. This same trend exists in comparing the results obtained with the thickened fuels containing JP-4 and Jet A or JP-5. The overall ratings for

TABLE 1. - Proposed Crash Fire Hazard Rating System.

1. Minimum Temperature for Hot Surface Ignition

Minimum AIT by ASTM D2155-66 Method

Rating Value = $10\left(\frac{AIT-100}{1000}\right)$; Zero Rating at AIT $\leq$ 100°F; Maximum Rating (10) at AIT $\geq$1100°F

2. Minimum Temperature for Formation of Flammable Mixtures

Flash Point by Modified ASTM D-56-64 Method

Rating Value = $10\left(\frac{F.Pt.}{200}\right)$; Zero Rating at F.Pt. $\leq$ 0°F; Maximum Rating (10) at F.Pt. $\geq$200°F

3. Relative Volatility Rate or Time for Formation of Flammable Mixtures

Time to attain 1/2 psig at 100°F by modified Reid Vapor Pressure Method, ASTM D323-58.

Rating Value = $10\ (1 - 2.5/t)$; Zero Rating at $t \leq 2.5$ min.

4. Relative Self-Spread Rate

Rate of self spread following ignition in "Slope Test" at 70°F

Rating Value = $15\ (1 - R/5)$; Zero Rating at $R \geq 5$ in/sec.

5. Regression or Burning Rate of Bulk Fuel

Regression rate of fuel ignited in 8-in. diameter burning tray.

Rating Value = $10\left(1 - \frac{R}{0.1}\right)$; Zero Rating at $R \geq 0.1$ in/min.

6. Horizontal Flame Spread Rate Under Static Conditions

Horizontal flame spread rate of fuel ignited in 3 in. angle trough.

Rating Value = $10\ (1 - R/5)$; Zero Rating at $R \geq 5$ ft/sec.

7. Fire-Ball Size Under Impact Conditions

Height and width of fire ball in "Fuel Drop Fire Test" with 5 lbs of fuel at a drop height of 20 ft.

Maximum width (W_1) within 1 second after ignition:
Rating Value = $10\ (1 - W_1/20)$; Zero Rating at $W_1 \geq 20$ ft.

Maximum width (W_2) within 10 seconds after ignition:
Rating Value = $10\ (1 - W_2/20)$; Zero Rating at $W_2 \geq 20$ ft.

Maximum height (H_2) within 10 seconds after ignition:
Rating Value = $10\ (1 - H_2/12)$; Zero Rating at $H_2 \geq 12$ ft.

Table 2. - Summary of Experimental Data for JP-4 Liquid Fuel and Various JP-4 Thickened Fuels.1/

Property	JP-4 Liquid	JP-4 Gel 1.5% (Gel A)	JP-4 Gel 3% (Gel B)	JP-4 Emulsion 2% Emulsion D
1. AIT, °F	445 (1)	455 (1)	450 (1)	455 (1)
2. Flash Pt., °F	0 (1)	11 ± 5 (4)	3 ± 2 (2)	18 ± 2 (2)
3. Vapor Pressure at 100°F Time for 1/2 psig, min.	2.5 ± 0.1 (3)	7.2 ± 1.4 (5)	15 (1)	14.6 ± 4 (6)
4. Self Spread Rate, in/sec.	>50 (2)	1.5 ± 0.4 (25)	≤0.1 (1)	0.70 ± 0.05 (5)
5. Regression Rate, in/min.	0.08 ± 0.01 (10)	0.075 ± 0.005 (7)	0.09 ± 0.01 (2)	0.075 ± 0.005 (4)
6. Horizontal Flame Spread Rate, ft/sec.	7.3 ± 0.5 (2)	3.1 ± 0.2 (3)	3.6 ± 0.5 (2)	2.0 ± 1.5 (8)
7. Fire Ball under impact conditions				
Max. Width, ft (<1 sec)	19.0 ± 0.5 (2)	7.2 ± 1.2 (3)	9.0 ± 2.0 (2)	13.8 ± 2.0 (3)
Max. Width, ft (<10 sec)	19.0 ± .5 (2)	18.0 ± 4.5 (3)	14.5 ± 2.1 (2)	16.1 ± 1.4 (3)
Max. Height, ft (<10 sec)	11.3 ± .7 (2)	6.4 + 3.2 (3)	7.8 ± 1.0 (2)	9.5 ± 2.3 (3)

1/ Numbers in parentheses indicate number of trials.

Table 3. - Summary of Experimental Data for Jet A Liquid Fuel and Various Jet A or JP-5 Thickened Fuels.[1/]

Property	Jet A Liquid	Jet A Gel 1.5% (Gel A)	JP-5 Gel 3% (Gel B)	Jet A Gel 6.9% (Gel C)
1. AIT, °F	435 (1)	455 (1)	440 (1)	455 (1)
2. Flash Pt., °F	141 ± 1 (3)	142 (1)	108 ± 8 (5)	142 ± 1 (2)
3. Vapor Pressure at 100°F, psig	0.33 at 25 min.	0.27 at 25 min.	0.28 at 25 min	--
4. Self Spread Rate, in/sec.	>50 (2)	0.45 ± 0.15 (6)	0.13 ± 0.1 (4)	0.16 (1)
5. Regression Rate, in/min.	0.08 (1)	0.07 (1)	0.06 (1)	0.065 (1)
6. Horizontal Flame Spread Rate, ft/sec.	≤0.01 (2)	0.025 ± 0.01 (4)	0.01 ± 0.005 (3)	0.01 (1)
7. Fire Ball under impact conditions				
Max. Width, ft (<1 sec)	9.7 ± 0.4 (3)	2.5 ± 1 (3)	.7 (1)	--
Max. Width, ft (<10 sec)	9.7 ± 0.4 (3)	2.5 ± 1 (3)	2.0 (1)	--
Max. Height, ft (<10 sec)	3.6 ± 0.3 (3)	2.4 ± 0.5 (3)	2.4 (1)	--

1/ Numbers in parentheses indicate number of trials.

Table 4. - Comparison of Various Fuels According to the Proposed Fire Hazard Rating System.

Fuel Property	Liquid Fuel JP-4	Liquid Fuel Jet A	Gel 1.5% Gel A JP-4	Gel 1.5% Gel A Jet A	Gel 3% Gel B JP-4	Gel 3% Gel B JP-5	Emulsion 2% Emulsion D JP-4
	Rating Values						
1. Min. AIT	3.5	3.4	3.6	3.6	3.5	3.4	3.6
2. Flash Point	0	7.1	0.6	7.1	0.2	5.4	0.9
3. Volatility Rate	0.4	10.0	6.5	10.0	8.3	10.0	8.3
4. Self Spread Rate	0	0	10.5	13.7	15	14.6	12.9
5. Regression Rate	2.0	2.0	2.5	3.0	1.0	4.0	2.5
6. Flame Spread Rate	0	10.0	3.8	10.0	2.8	10.0	6.0
7. Fire Ball under impact conditions							
Width - <1 sec	0.5	5.1	6.4	8.7	5.5	9.7	3.1
Width - <10 sec	0.5	5.1	1.0	8.7	2.7	9.0	1.9
Height - <10 sec	0.6	7.0	4.7	8.0	3.5	8.0	2.1
Total Rating Value	7.5	49.7	39.6	72.8	42.5	74.1	40.3

the JP-4 gels (A and B) and the JP-4 emulsion (D) are all close to 40 as compared to over 70 for the Jet A or JP-5 gelled materials. The rating for the JP-4 fuel is only 7.5. Since the Jet A has a rating of approximately 50, it rates higher than even the JP-4 thickened fuels that were examined. The low ratings for the JP-4 thickened fuels are largely attributed to their low flash points, high flame spread rates under static conditions, and poor performance in the "Fuel Drop Fire Test" (Items 2, 6 and 7). Of the thickened fuels, the JP-4 emulsion displayed the greatest flame spread hazard in the "Fuel Drop Fire Test." At the same time, results found under non-impact conditions indicate that the fire hazard associated with this emulsified fuel is less than that for the two JP-4 gelled fuels.

The radiation data that were obtained also indicated that the fire ball hazard under impact conditions is greater for the JP-4 fuels than for the Jet A fuels. Table 5 compares the maximum radiation intensities that were recorded within 1 and 10 seconds after ignition in several of the fuel drop experiments. As noted, the recorded values for the JP-4 fuel ($\sim$500 milliwatts/cm^2) were approximately 10 times greater than those for the Jet A fuel over both of the given time intervals. The ratios of their radiation values are greater than those indicated by their fire ball measurements in tables 2 and 3. This trend is even more pronounced in comparing the data for JP-4 and the thickened fuels or the data for the thickened fuels alone. Accordingly, the fire-ball hazard ratings tend to be lower for the JP-4 thickened fuels and higher for the Jet A thickened fuels if this particular rating is based on the radiation measurements instead of the fire-ball size measurements.

Table 5. - Comparison of Thermal Radiation Data from Fuel Drop Fire Experiments with Various Fuels.

Fuel	Maximum Radiation Intensity 1/ milliwatts/cm^2	
	Within 1 sec after ignition	Within 10 sec after ignition
Liquid fuel		
JP-4	460 (1)	540 (1)
Jet A	50 ± 8 (2)	50 ± 8 (2)
Emulsion, D		
JP-4	36 ± 10 (2)	120 ± 35 (2)
Gel, A		
JP-4	13 ± 8 (2)	105 ± 51 (2)
Jet A	~0 (1)	< 5 (1)
Gel, B		
JP-4	15 ± 5 (2)	165 ± 51 (2)
Jet A	~0 (1)	5 (1)

1/ Numbers in parentheses indicate number of experiments; measurements made at 30 feet from point of impact and ignition.

CONCLUSIONS

It is concluded that:

1. A rating system was developed that is useful for comparing the potential crash fire hazard of thickened hydrocarbon fuels under laboratory-scale conditions; the rating system is designed primarily for screening candidate thickened fuels for possible use in aircraft.

2. The numerical ratings are apparatus dependent and provide a relative comparison of the overall flammability hazard for the fuels at rest and under certain impact conditions; the reference base value for each fuel property rating was selected to give a zero or low rating for the JP-4 liquid fuel.

3. The hazard associated with flame spread and fire intensity can be expected to be greater under full-scale fire conditions.

RECOMMENDATIONS

It is recommended that:

1. The potential crash fire hazard of the candidate thickened fuels, including those under investigation by the U.S. Army, be compared under various impact conditions.

2. The fire hazard of the thickened fuels be investigated under simulated flight conditions and as a function of the yield stress of the fuel.

3. In addition, the fire extinguishing requirements for these fuels be compared under laboratory and near full-scale fire conditions.

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4. Private communication.

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APPENDIX

Crash Fire Hazard Rating System Test Procedures

1. Minimum Temperature for Hot Surface Ignition

Minimum autoignition temperatures of the fuels are determined in air by the standard ASTM D2155-66 method (Ref 8) with two minor modifications. (1) The thickened fuels are taken at room temperature (70° ± 10°F) and passed through a wire screen of approximately 10 mesh prior to use and (2) they are injected into the test flask (200 cc Pyrex Erlenmeyer) with the needle of the hypodermic syringe removed. These modifications are recommended to facilitate fuel injection and they should have little or no effect on the minimum AIT's expected for the fuels of interest.

2. Minimum Temperature for Formation of Flammable Mixtures

Flash points of the fuels are determined by the ASTM D56-64 method (Tag Closed Cup) (Ref 10) with certain modifications in procedure. The thickened fuels have relatively low thermal conductivity and fluidity and, therefore, considerable thermal lag can exist between the fuel sample and the sample container or bath in a flash point tester. A low heating rate of approximately 0.3°F/min is required to overcome this difficulty and to obtain a uniform sample temperature. For the JP-4 type thickened fuels, the Tag Closed Cup apparatus must be modified to permit circulation of low temperature fluids. This was done by adding an inlet port opposite to the outlet port and near the bottom of the bath container; also, the sides of the bath container are covered with insulation to reduce heat leaks. In a determination, the sample is cooled to 20°F below the expected flash point. A bath temperature equal to or slightly below the sample temperature is necessary to allow for heat loss differences and to achieve the optimum heating rate of 0.3°F/min. The thickened fuels should be passed through a 1/4-inch or ~No. 3 wire mesh screen before use.

3. Relative Volatility Rate or Time for Formation of Flammable Mixtures

Modifications of the ASTM Reid Vapor Pressure Test Method (ASTM D323-58) (Ref 11) are made to compare the relative rates at which fuels form flammable vapor-air mixtures at 100°F. The time required for a fuel to attain a vapor pressure of 1/2 psig was selected since the corresponding fuel concentration will fall well within the flammable range for the fuels of interest. The data are obtained by a method similar to that of the Standard ASTM procedure but with a few exceptions. Liquid fuels are loaded into the sample chamber according to the ASTM procedure, but thickened fuels are loaded by means of a cooled piston-type injector (32°F). The fuels, precooled to 32°F, are forced through an ~No. 3 wire mesh and through a nozzle extending to the bottom of the chamber. This chamber is maintained at 32°F and is immediately assembled with the air chamber which is at a temperature of 100°F; the chambers are fitted with a screw-type connector for quick

assembly. The air chamber and the fuel container are not shaken during a determination and precautions are taken to prevent any liquid spill from the fuel container into the air chamber. Pressure measurements are made using a transducer although precision type Bourdon gages can also be used.

4. Relative Self-Spread Rate

A "Slope Test" was designed to measure the relative ease with which a thickened fuel, once ignited, can soften and flow to increase the potential size of the fire. In this test, a 4-foot long metal trough, sloped at a 2° angle, is used; 3-inch aluminum angle is recommended for the trough. One and one-half inches of the upper end of the trough is filled evenly with the fuel and the top surface of the fuel is ignited with a torch. For fuels that do not hold in place, an aluminum V-shaped wedge contains the fuel until it is ignited. In the case of the kerosine-type fuels, a wick is required to ignite the fuel; a 1-inch length of 8 mm pipe stem cleaner is adequate. The time required for the fuel to travel 2 feet down the trough is then measured from the time of ignition. Fuel and ambient temperatures should be 70° ± 5°F and the thickened fuels should be passed through an ~No. 3 wire mesh before use.

5. Regression or Burning Rate

The regression or burning rates of the fuels are determined in 8-inch diameter metal trays with a total depth of 1-1/2 inches. Aluminum or steel trays are recommended and they should be filled to a height 1/2 inch from the top. Any irregular or uneven fuel surfaces are leveled to provide a uniform surface area and the fuel is ignited by a torch. The average regression rate is determined by measuring the burning time for a fuel depth of 1 inch. The rates can be measured by visual observation, by pressure-load transducers, or by other devices whose output can provide a change of fuel weight and fuel depth with time. Fuel and ambient temperatures should be 70° ± 10°F.

6. Horizontal Flame Spread Rate Under Static Conditions

The flame spread rates should be determined in a metal trough at least 4-1/2 feet in length; 3-inch aluminum angle is recommended for this test. The trough is filled with the thickened fuel (or liquid fuel) and any irregular or uneven fuel surfaces are leveled to provide a uniform surface area. The fuel is ignited with a torch at one end of the trough and flame propagation is measured over a 4-foot distance. Flame propagation can be measured by the use of fuse wires (1/2 amp) and a suitable timer or recorder; the first fuse wire should be about 6 inches from the point of ignition. Fuel and ambient temperatures should be 70° ± 5°F and the thickened fuels should be passed through an ~No. 3 wire mesh before use.

7. Fire-Ball Size or Radiation Intensity Under Impact Conditions

A "Fuel Drop Fire Test" was designed for comparing the relative fire hazard which may be associated with the fuels in ignitions under impact conditions. For this purpose, 5 pounds of fuel contained in a 3000-ml Pyrex flask is dropped from a height of 20 feet onto a concrete or asphalt surface; the shape of the flask appears to be unimportant since the results are essentially the same with Erlenmeyer and round bottom flasks. A torch is positioned near the point of impact to effect immediate ignition and is removed after ignition. The flame spread and size of fire ball produced are recorded by a motion picture camera; a metal frame grid is mounted in the background to facilitate the fire ball measurements. The maximum width of the fire ball within 1 second is measured to observe flame spread differences which can be attributed to increased vapor formation, mist formation, or fuel spread under impact conditions. The maximum height and width attained within 10 seconds are also measured. An alternate method for comparing the fire ball hazard is the measurement of the thermal radiation. A bismuth-silver thermopile equipped with a calcium fluoride window is mounted 3 feet above ground level and 30 feet from the point of impact. Output of the thermopile is recorded by a direct writing oscillograph. Fuel and ambient temperatures should be 70° ± 10°F and the thickened fuels should be passed through an ~No. 3 wire mesh before use. In addition, the experiments should be conducted under minimum wind conditions because of the great effect this factor can have on the flame spread.