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Flammability Measurements on Fourteen Different Hydraulic Fluids Using A Temperature-Pressure Spray Ignition Test

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National Engineering Laboratory
U.S. Department of Commerce
National Bureau of Standards
Washington, DC 20234

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Final Report

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Sponsored in part by
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NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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FLAMMABILITY MEASUREMENTS ON FOURTEEN DIFFERENT HYDRAULIC FLUIDS USING A TEMPERATURE--PRESSURE SPRAY IGNITION TEST

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Abstract

This report describes a spray ignition flammability test procedure which was developed and designed to be used as an alternative to the spray ignition test used by the Mine Safety and Health Administration (MSHA) to qualify hydraulic fluids for use in underground coal mines. The test procedure allows for quantitative measurement of heat and energy developed by fluids which may ignite in the test and provides for rank ordering of fluids according to their flammability. The testing program included currently used fluids such as invert emulsions, synthetics, and water glycols. Studies showed that the water glycol fluids were the only fluid type to resist ignition by spray testing. All other fluid types were ignited and in some cases produced considerable flaming.

Key words: Spray ignition; flammability resistance; temperature rise; heat flux; pressure.

1. INTRODUCTION

The Center for Fire Research at the National Bureau of Standards (NBS) in work conducted for the Bureau of Mines (BOM) and Mine Safety and Health Administration (MSHA), made an evaluation of the three different test methods used by MSHA (under Code of Federal Regulations Schedule 30 Part 35) for measuring the flammability of hydraulic fluids intended for use in specific underground coal mining operations.

In the course of working with one of these test methods (Temperature--Pressure Spray Ignition Test) the Center developed a new and different approach to the measurement of flammability when a fluid is sprayed into an open flame ignition source. The new testing procedures call for the measurement of temperature rise (°C) and energy (heat flux W/cm^2) generated by fluids which ignite and produce flaming in the test. The following report discusses the results obtained in this study.

2. TEST MATERIALS

A total of 14 different hydraulic fluids were selected for testing. Included were two water glycols, seven synthetics and five invert emulsions. The fluids were obtained from manufacturers who normally supply these materials to the underground coal mining industry and who report that the fluids are fire resistant under the Code of Federal Regulation Schedule 30 Part 35 Flammability Regulations.

Invert emulsions are hydraulic fluids that consist of water in an oil emulsion in which the water content may vary from 40 to 95 percent. Synthetics are fluids which contain organic esters (e.g., phosphates) or synthesized hydrocarbons while water glycols consist of a water-glycol solution with at least 35 percent water.

Table 1 lists the specific gravity and viscosity values measured for the test fluids. At room temperature, specific gravities ranged from 0.91 to 1.20 g/cm^3 and viscosities ranged from 38 to 417 centistokes. At 37.7°C (100°F) viscosity values measured 21 to 168 centistokes and at 65°C (150°F) values from 10 to 53 centistokes were recorded.

3. TEST EQUIPMENT

Figure 1 shows a schematic diagram of the apparatus used for conducting the spray ignition tests. The system consists of an atomizing round spray nozzle (Binks model no. F-12-25) having a discharge orifice of 0.64 mm (0.025 in) diameter, capable of discharging 12.4 liters (3.28 gallons) of water per hour (GPH) with a spray angle of 90 degrees at a pressure 689 Kpa (100 psi). The nozzle is connected to a stainless steel "T" connector fitted with a shielded chromel-alumel thermocouple and to 6.4 mm (1/4 in O.D.) stainless steel tubing which connects to a solenoid valve, a pressure transducer and to a 1000 cm^3 capacity sample cylinder. The sample cylinder is also fitted with a thermocouple and is connected to a pressure relief valve and to a pressurized nitrogen cylinder equipped with appropriate valves and regulators.

Table 1. Viscosity of hydraulic fluids at various temperatures

Fluid No.	Type	Specific Gravity gm/cu cm	Viscosity (Centistokes) Deg (C) 21-24	37.7	65
1	Water Glycol	1.08	82	46	22
2	Water Glycol	1.06	83	52	23
3	Synthetic	0.99	191	94	32
4	Synthetic	1.14	263	88	24
5	Invert Emulsion	0.92	153	86	34
6	Synthetic	1.14	417	168	37
7	Invert Emulsion	0.94	120	76	25
8	Synthetic	1.20	38	21	10
9	Synthetic	1.13	144	54	18
10	Synthetic	1.15	95	45	15
11	Invert Emulsion	0.91	231	134	53
12	Synthetic	1.14	118	60	18
13	Invert Emulsion	0.93	290	130	52
14	Invert Emulsion	0.92	162	90	38

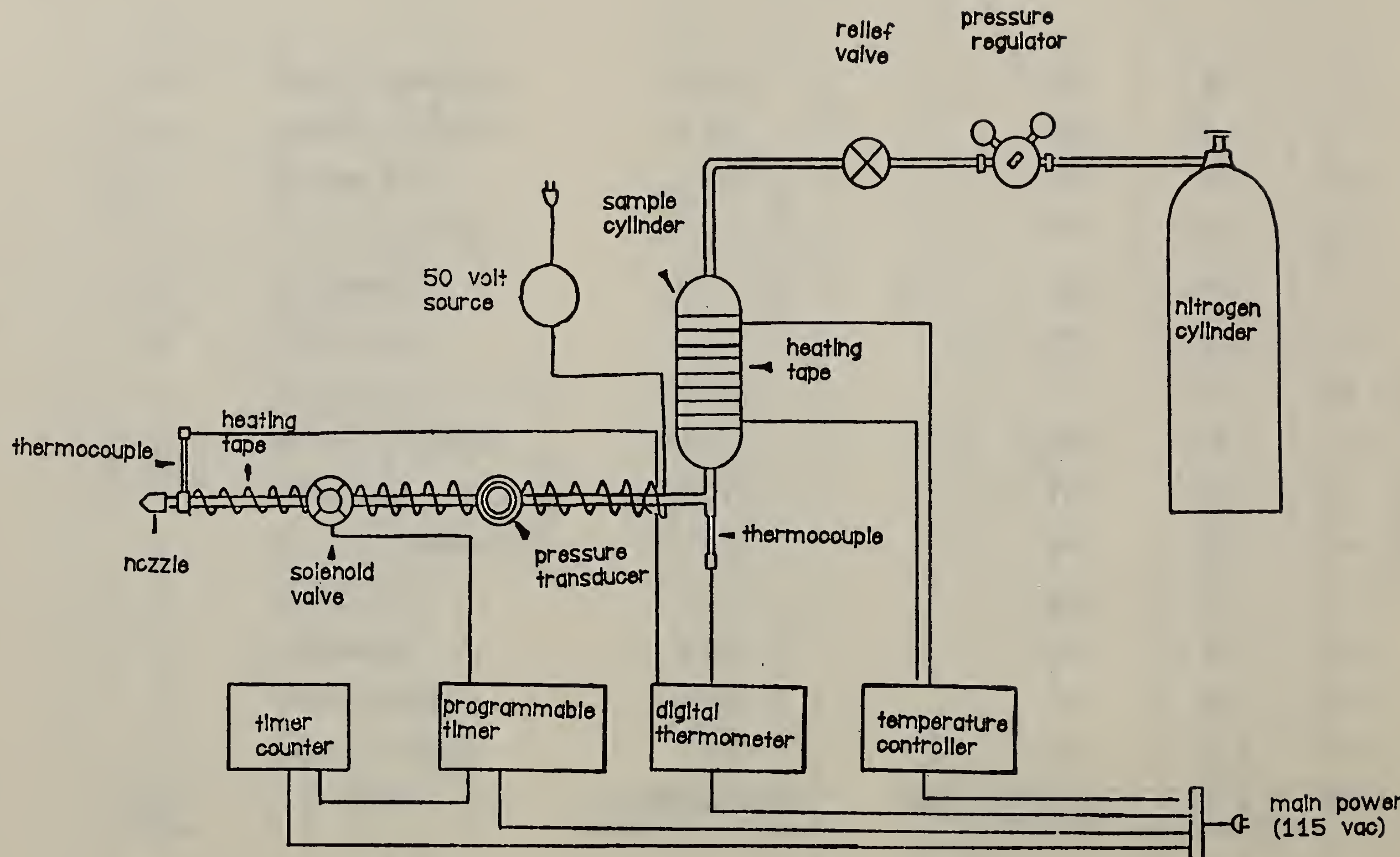

FIGURE 1
SPRAY IGNITION TEST APPARATUS

The sample cylinder and all tubing leading to the spray nozzle are wrapped with heating tape. The heating tape is controlled by a temperature controller to insure that the temperature of the test fluid is generated at 65°C. Autotransformers are used to reduce the current to the heating tape so that fluid passing through the wrapped tubing exits the nozzle at the test temperature. Other equipment includes a programmable timer, timer counter, and digital thermometer.

Figure 2 shows the arrangement of 9 C/A thermocouples [2.5 mm (0.01 in) diameter] mounted in ceramic tubing and connected in parallel. The thermocouples form a 10 cm (4 in) diameter circle in the 20 x 20 cm (8 x 8 in) opening of the exhaust port of the test chamber which is located 90 cm (36 in) downstream from the spray nozzle tip and 135 cm (54 in) from the deck (or floor) of the test cabinets (see figure 3).

A water-cooled heat flux transducer (Medtherm Corporation, model no. 64-1-20) was used for making energy (W/cm^2) measurements. Figure 3 shows the transducer mounted in one of the sliding doors of the test cabinet. When the door is closed for test the transducer is located 68 cm (27 in) downstream from the spray nozzle and is 43 cm (17 in) above the deck of the cabinet. Internal L x W x H dimensions of the test cabinet were approximately 155 x 80 x 135 cm (62 x 32 x 54 in). The length was chosen to accommodate the maximum distance traveled by a spraying fluid. The end sections, back, and sliding front door panels of the test chamber were made of 5 mm (1/8 in) thick aluminum metal plate. The cabinet was fitted with a hood and exhaust system to remove smoke and gases produced by testing.

Cotton cheesecloth soaked by 50 cc of kerosene was used as the ignition source during test. The 50 gram sample of cheesecloth was folded into layers to fit a 48 x 5 x 5 cm (18 x 2 x 2 in) deep stainless steel metal trough fitted with a movable lid attached to its side (see figure 3A) which is used for quenching the flaming source after a test. Note: The cotton cheesecloth was type II class 2, 36 in Fed. Supply No. 8305-00-205-3496.

A Tektronix 4051 computer was used to record the output of the thermocouples and heat flux meter during a test. Data was collected every second and curves of temperature rise and heat flux versus time (sec) were provided by the computer. (Note: A pen type recorder might also be used to record test data.)

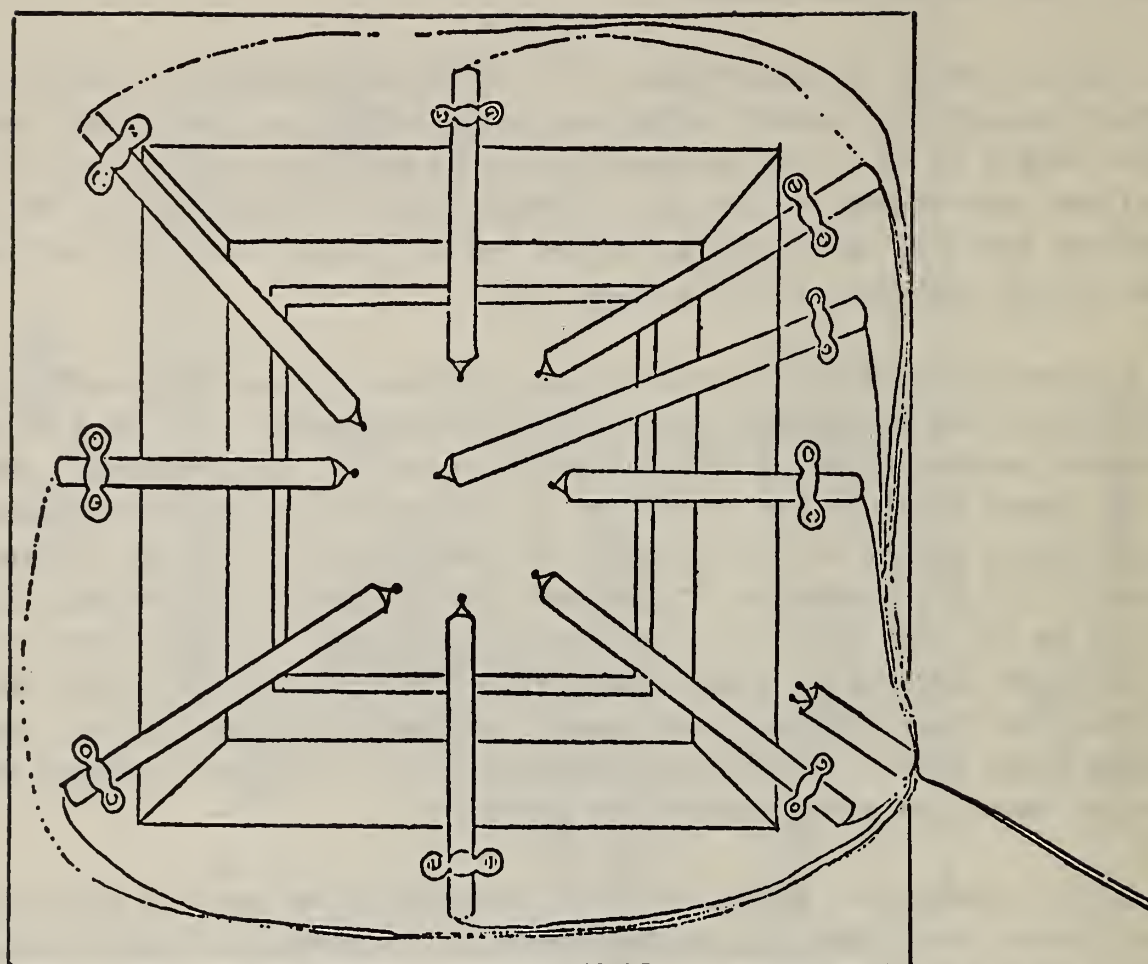

FIGURE 2
THERMOCOUPLE ARRANGEMENT FOR SPRAY IGNITION TEST

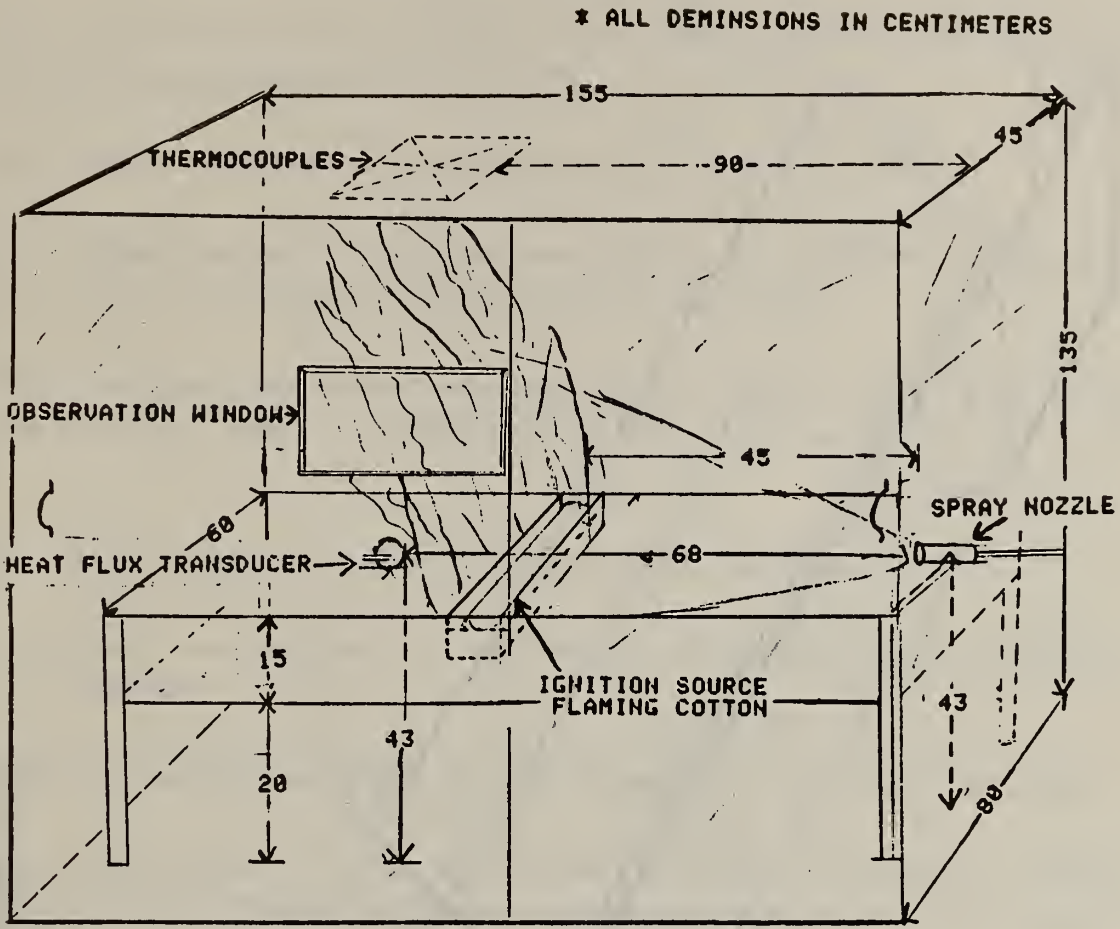

FIGURE 3
SPRAY IGNITION TEST CABINET

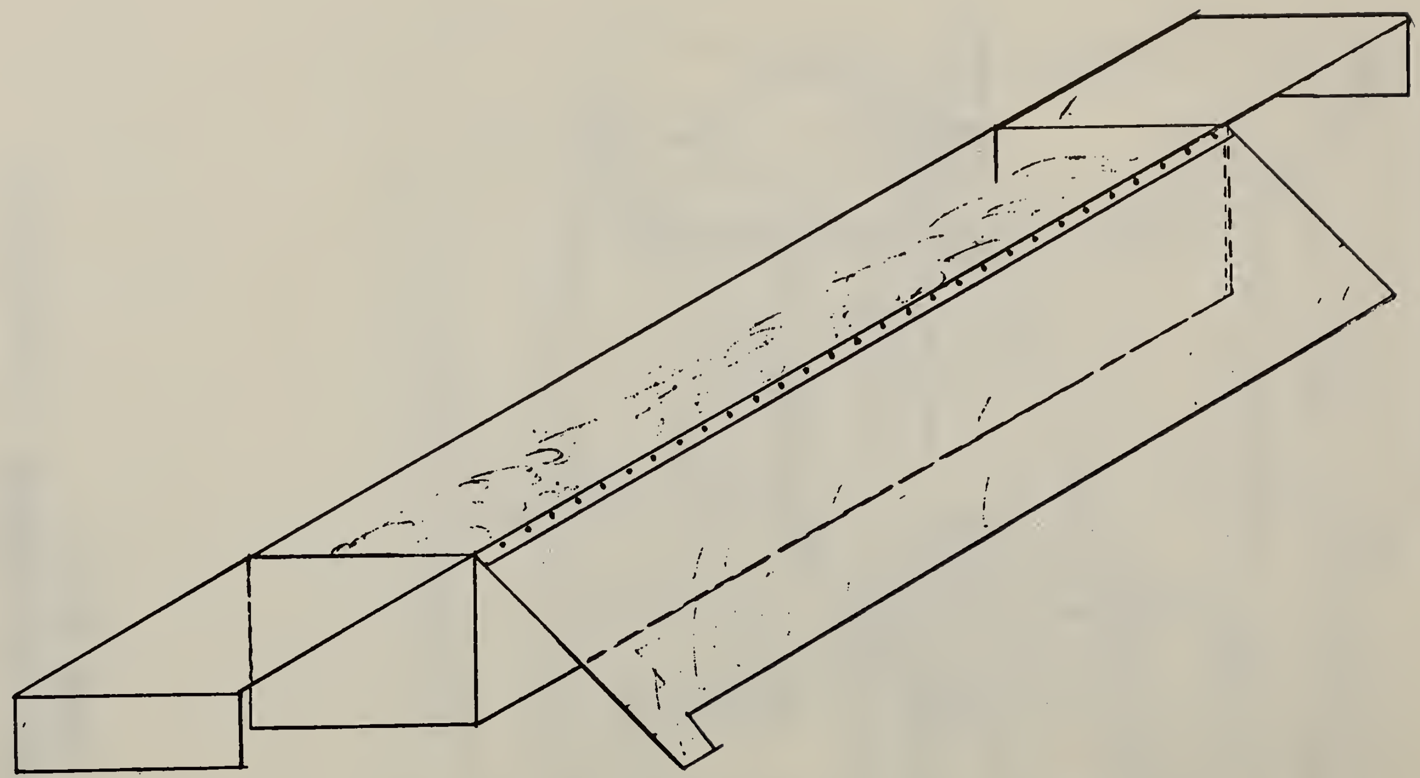

FIGURE 3(A)

METAL TROUGH FOR FLAMING COTTON IGNITION SOURCE

4. TEST PROCEDURES

The spray ignition tests were conducted in the following manner:

- Test hydraulic fluid was added to the sample cylinder and was heated to the testing temperature of 65°C (150°F).

- The filled cylinder was pressurized to 1,034 Kpa (150 psi).

- The exposed surface of cotton cheesecloth in the metal trough was wetted with 50 cc of kerosene streaming from a pipette.

- After wetting, the cotton was ignited and allowed to develop a flame front along the full length of the trough with a flame height of 10-15 cm (4-6 in).

- The spray nozzle was opened and the timer started.

- Test fluid was sprayed into and across the flaming ignition source for up to 30 seconds.

- Computer records were made of the temperature rise and heat flux.

- After completion of tests on a fluid, the sample cylinder, tubing, and spray nozzle were flushed with detergent treated water and the nozzle was inspected and cleaned before a new fluid was tested.

5. TEST RESULTS

Table 2 lists the fluids tested, their viscosities [at the testing temperature of 65°C (150°F)] and the temperature rise and heat flux values recorded after 10 seconds of test and at their peak values reached during the 30-second spray ignition test.

Figures 4, 5, 6, 7, 8, and 9 are presented as typical computer records made for a test on one of each of the different fluids tested. Shown are plots of temperature rise and heat flux data, respectively, against time (sec).

Table 2. Relation of hydraulic fluid viscosity to flammability

		@ 10 sec		Peak Temp Rise		Peak Heat Flux	
Fluid No.	Vis. CSS	Temp. Rise Deg C	H.F. W/cm^2	Temp. Deg C	Time-Peak sec	H.F. W/cm^2	Time-Peak sec
			Water Glycol Fluids				
1	22	0*	.02*	2	30*	.03*	26
2	23	5	.05	8	29	.06	22
			Synthetic Fluids				
8	10	140	.63	158	30	.70	16
10	15	107	.82	214	29	1.19	23
12	18	82	.71	242	27	1.09	27
9	18	70	.62	204	25	1.09	23
4	24	6	.10	53	29	.38	29
3	32	3	.09	12	28	.15	31
6	37	10	.17	99	30	.53	28
			Invert Emulsions				
7	25	34	.14	129	28	.43	26
5	34	17	.14	78	20	.36	30
14	38	216	1.37	296	17	1.48	16
13	52	218	1.58	286	19	1.59	16
11	53	128	.51	226	28	.85	11

* Average Values: (2-6 tests)

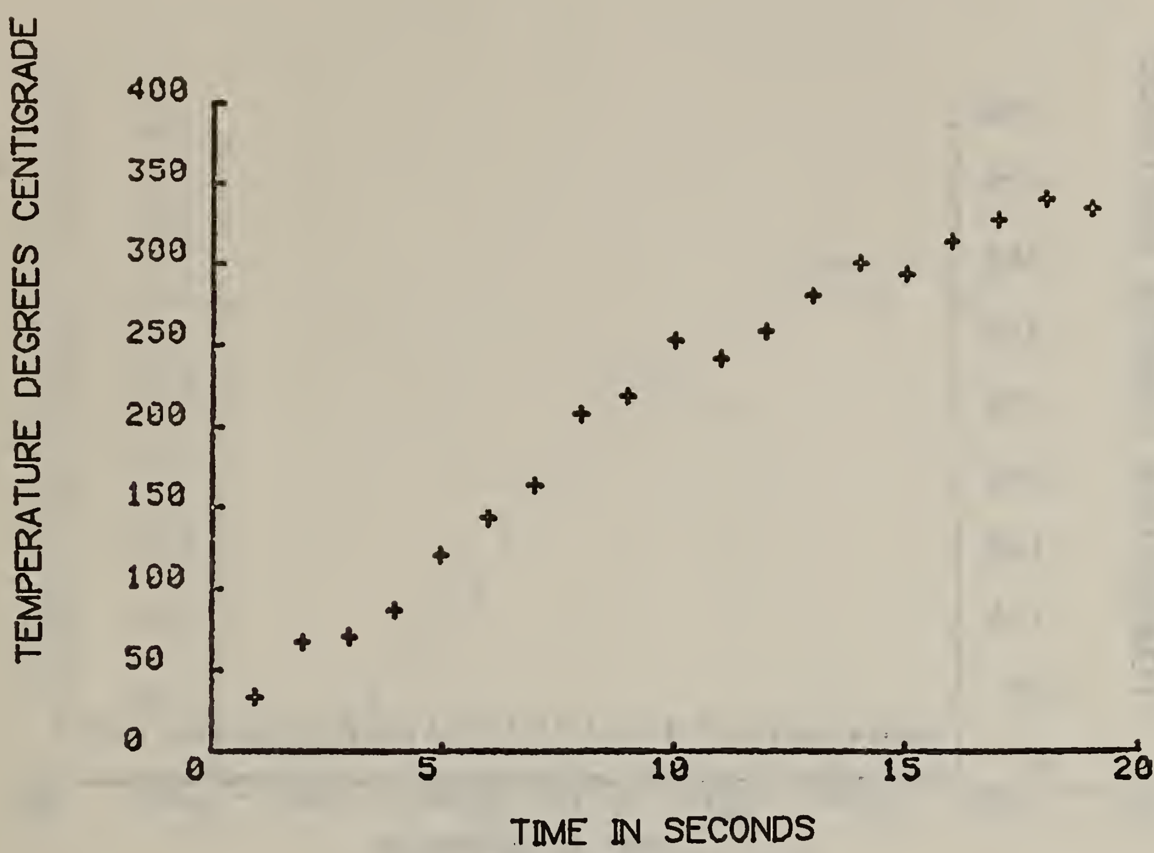

FIGURE 4

TEMPERATURE RISE - INVERT EMULSION FLUID NO. 14

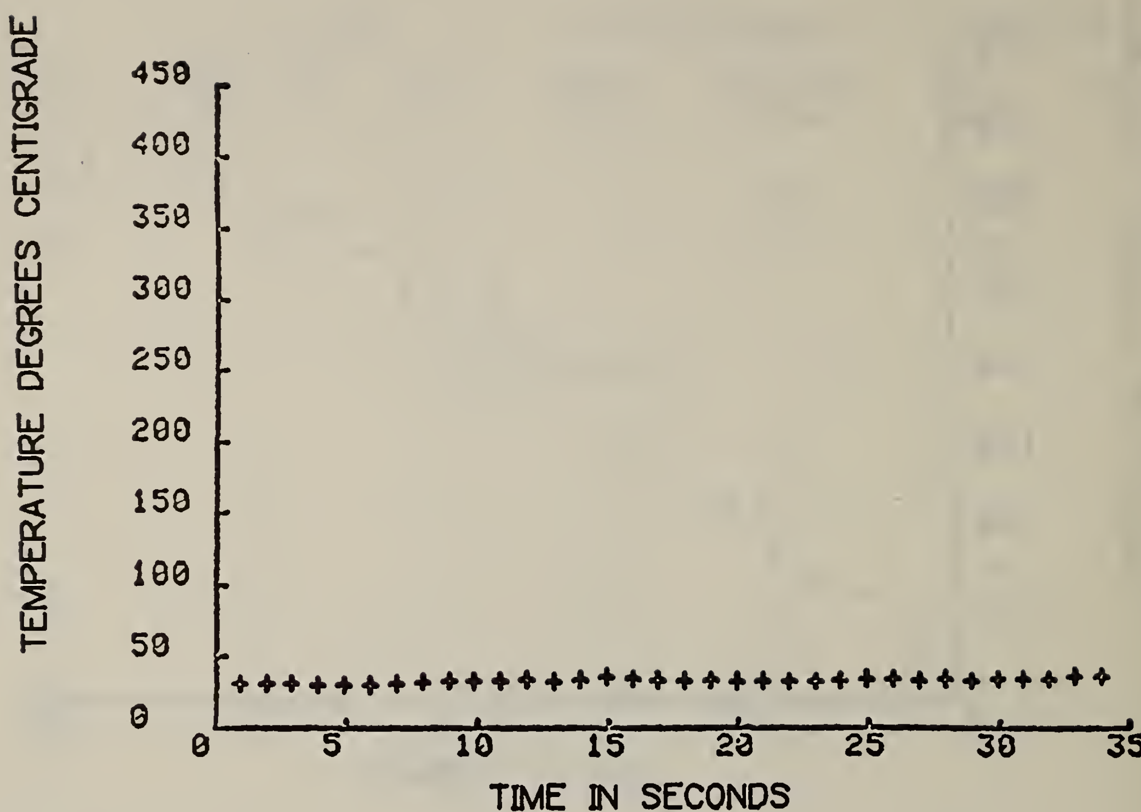

FIGURE 5
TEMPERATURE RISE - WATER GLYCOL FLUID NO. 1

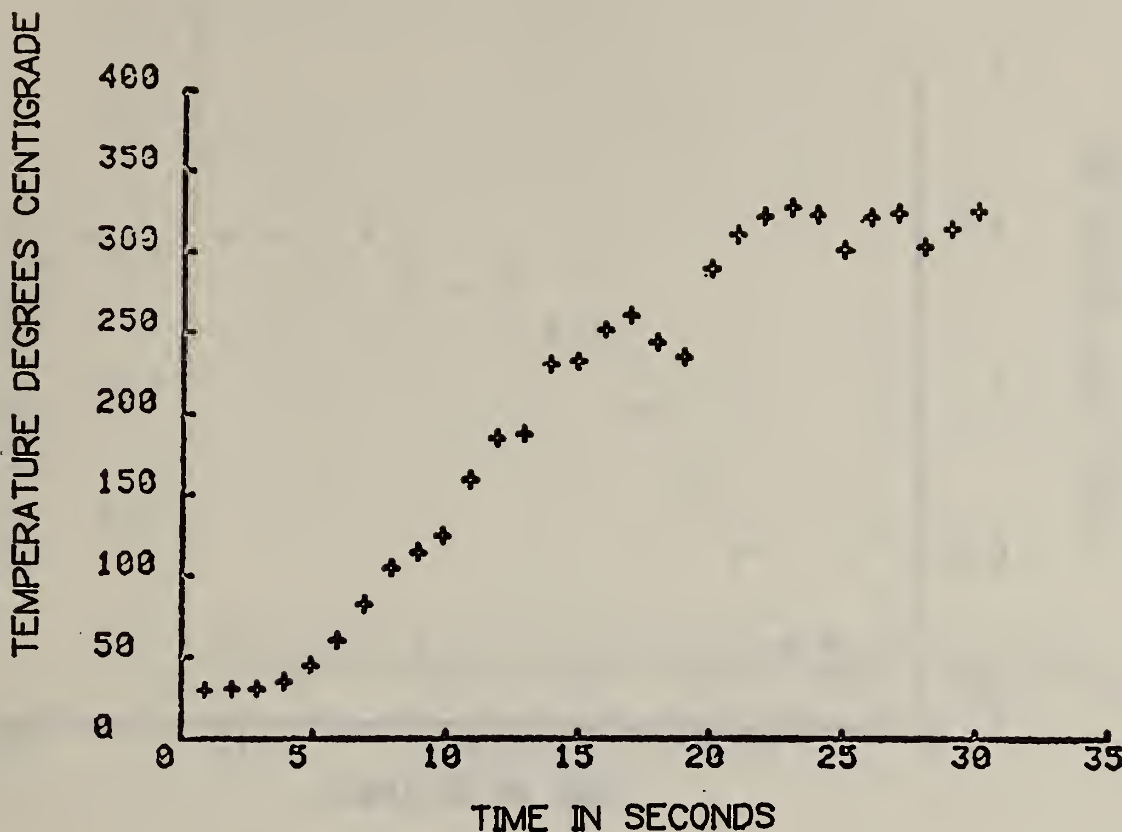

FIGURE 6

TEMPERATURE RISE - SYNTHETIC FLUID NO. 11

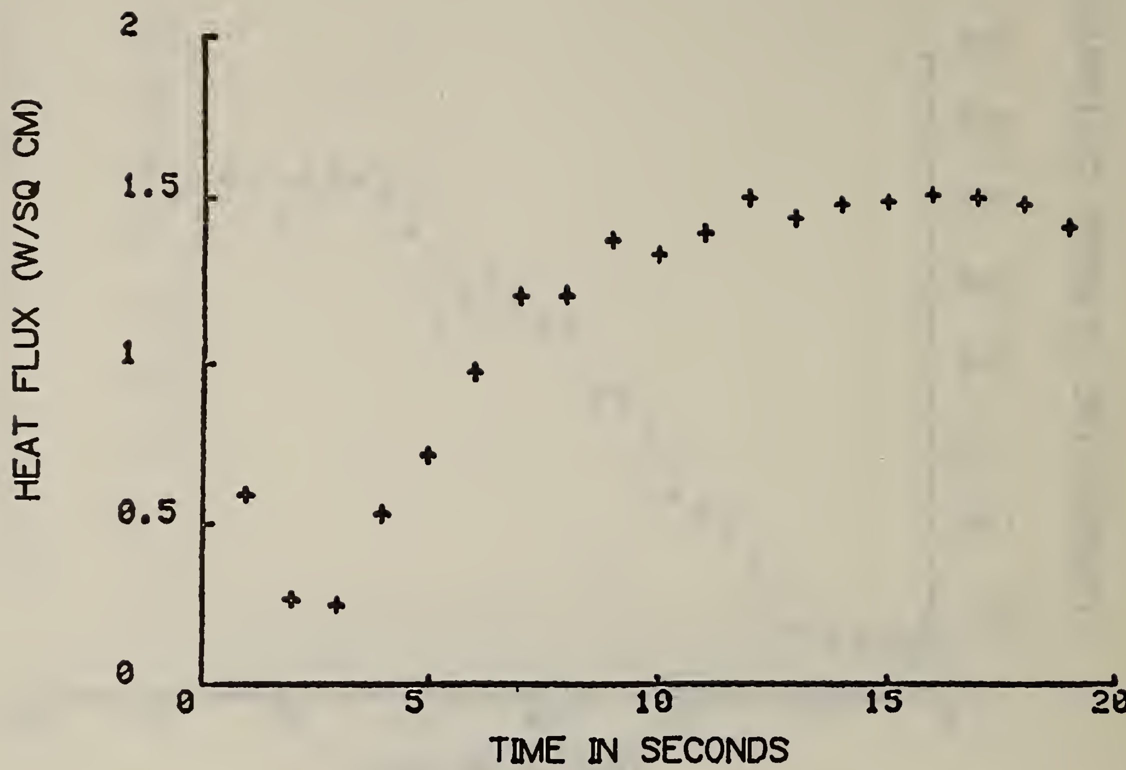

FIGURE 7
HEAT FLUX - INVERT EMULSION FLUID NO. 14

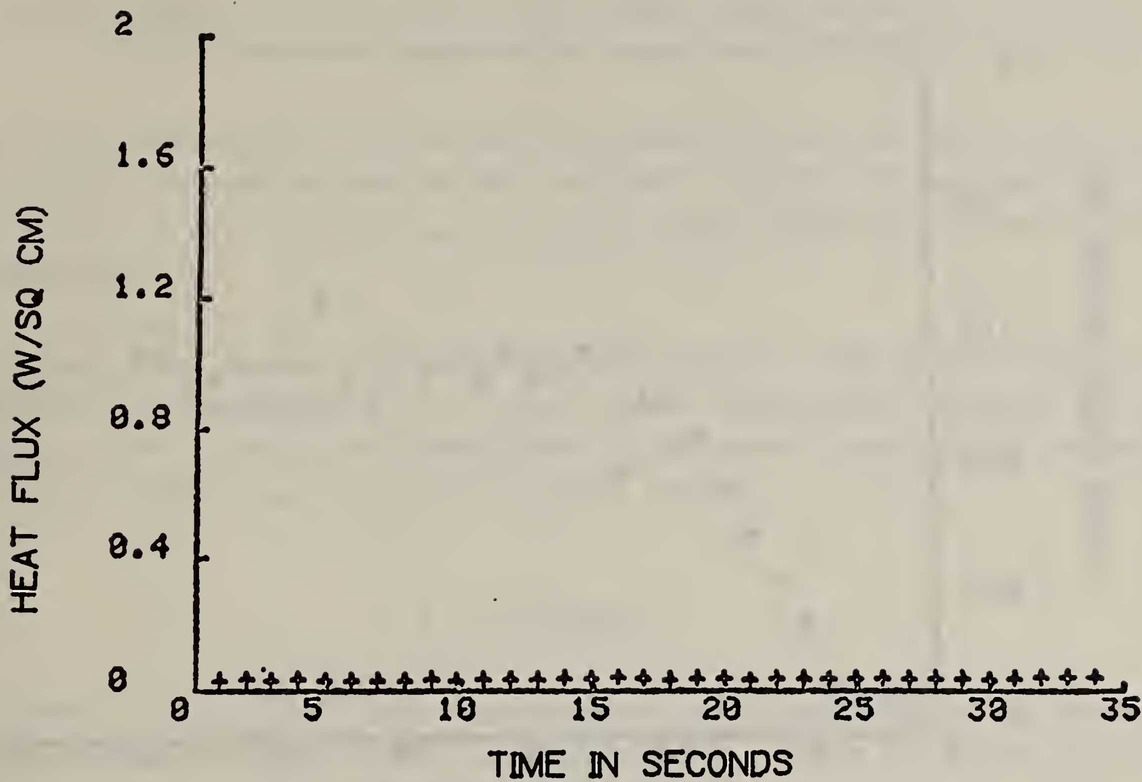

FIGURE 8
HEAT FLUX - WATER GLYCOL FLUID NO. 1

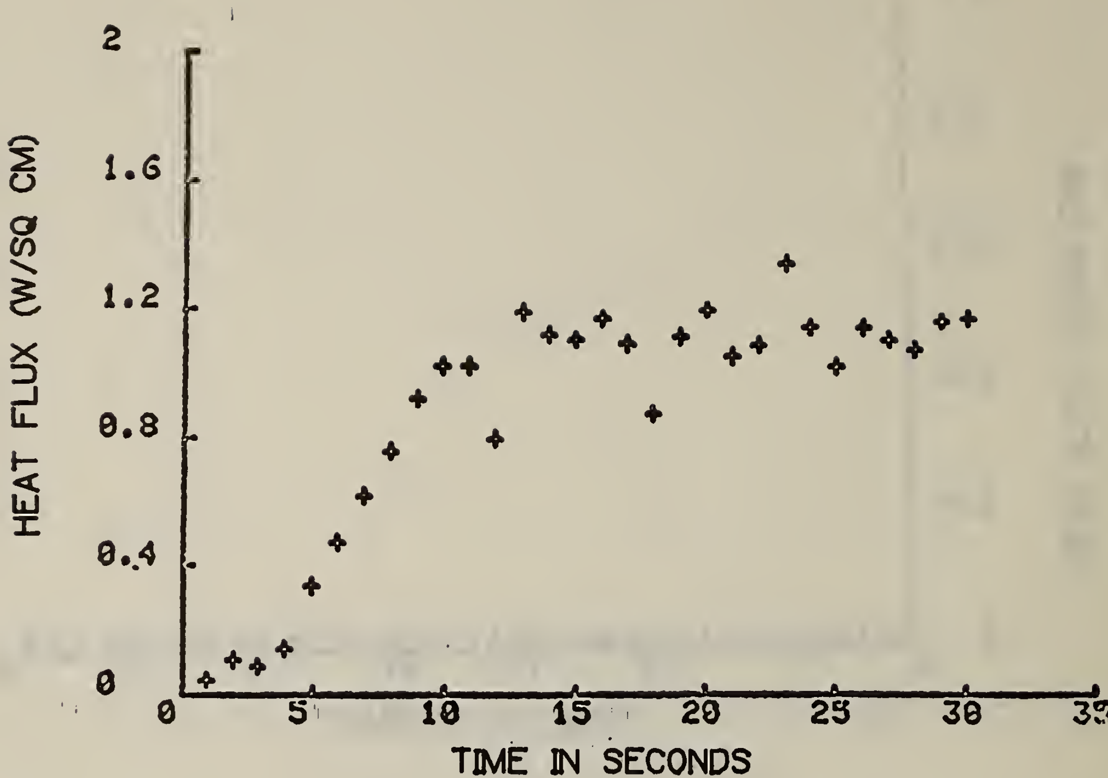

FIGURE 9
HEAT FLUX - SYNTHETIC FLUID NO. 11

An examination of the peak temperature rise data (compiled for all test fluids in table 2) shows that two water glycol fluids (nos. 1 and 2) and one synthetic fluid (no. 3) did not ignite or produce flaming. Ignitions, vigorous flaming, and significant temperature rise values were recorded for four synthetic fluids (nos. 8, 9, 10, and 12) and three invert emulsion fluids (nos. 11, 13, and 14) with measured temperature rises from 158-296°C (316-565°F).

Moderate temperature rise values were recorded for two synthetics (nos. 4 and 6) which produced values of 53°C and 99°C (126-210°F) and for two invert emulsions (nos. 5 and 7) which ignited and showed temperature rises of 78 and 129°C, respectively.

Peak heat flux values, as expected, followed the same rise patterns as were measured for temperature, e.g., the lowest values were recorded for the nonigniting water glycols and the highest values were observed for the fluids which produced high temperature rise values (296°C).

6. DISCUSSION

Figures 10, 11, and 12 show log-log plots of linear inverse relationships between hydraulic fluid viscosity and temperature. Plots for three temperature levels are shown for each of the three types of fluids, i.e., 21, 37.7, and 65°C (70, 100, and 150°F).

For the 14 different fluids tested these changes were significant, e.g., for a 17°C change (21-38°C) viscosity decreased 44-67 percent and for a 44°C change (21-65°C) the viscosities dropped to 71-91 percent of their original values.

The relation between a hydraulic fluid's flammability performance and viscosity is illustrated in figures 13 and 14 which show plots of temperature rise and heat flux, respectively, against different fluid viscosities. Here the invert emulsion fluids are generally shown to increase in fire propensity with increasing (or higher) viscosities, while the synthetics generally exhibit a decline in fire propensity as fluids with higher viscosities were tested. The water glycols showed no viscosity/flammability relationships for the lower viscosity range tested.

Maximum recorded values for temperature rises and heat flux, plotted in figure 15 shows good correlation between these parameters. This suggests

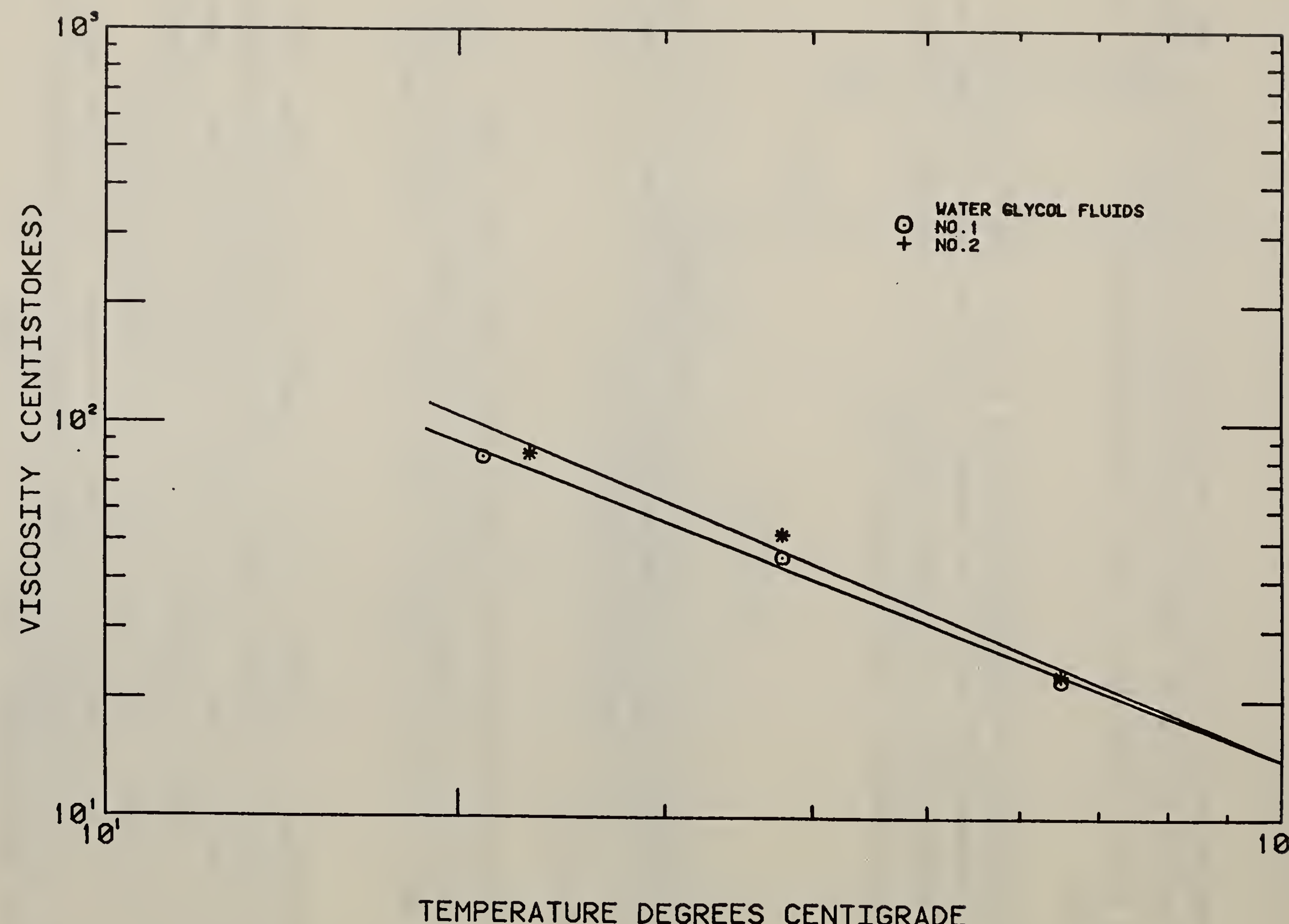

FIGURE 10
EFFECT OF TEMPERATURE ON VISCOSITY OF HYDRAULIC FLUIDS

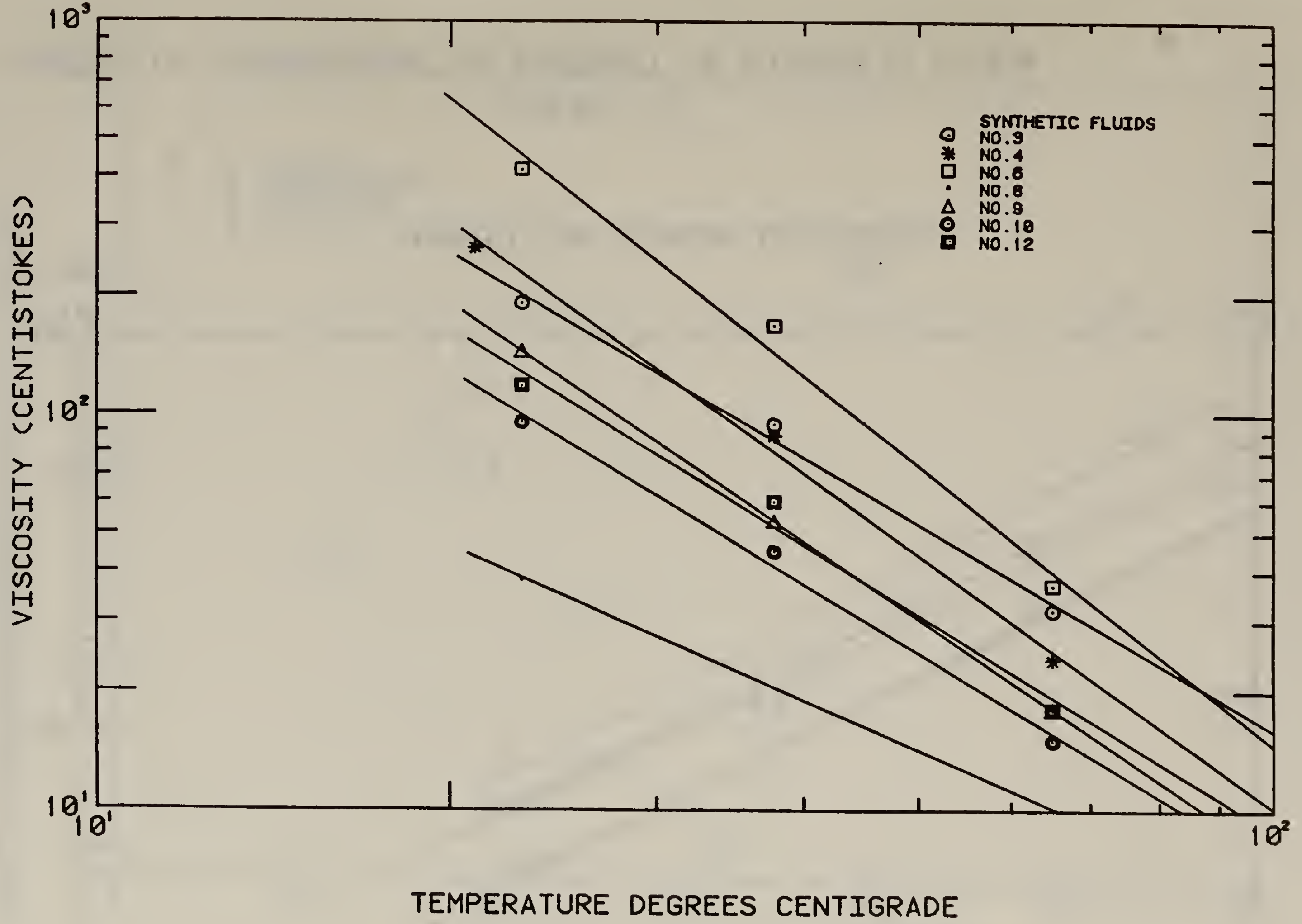

FIGURE 11
EFFECT OF TEMPERATURE ON VISCOSITY OF HYDRAULIC FLUIDS

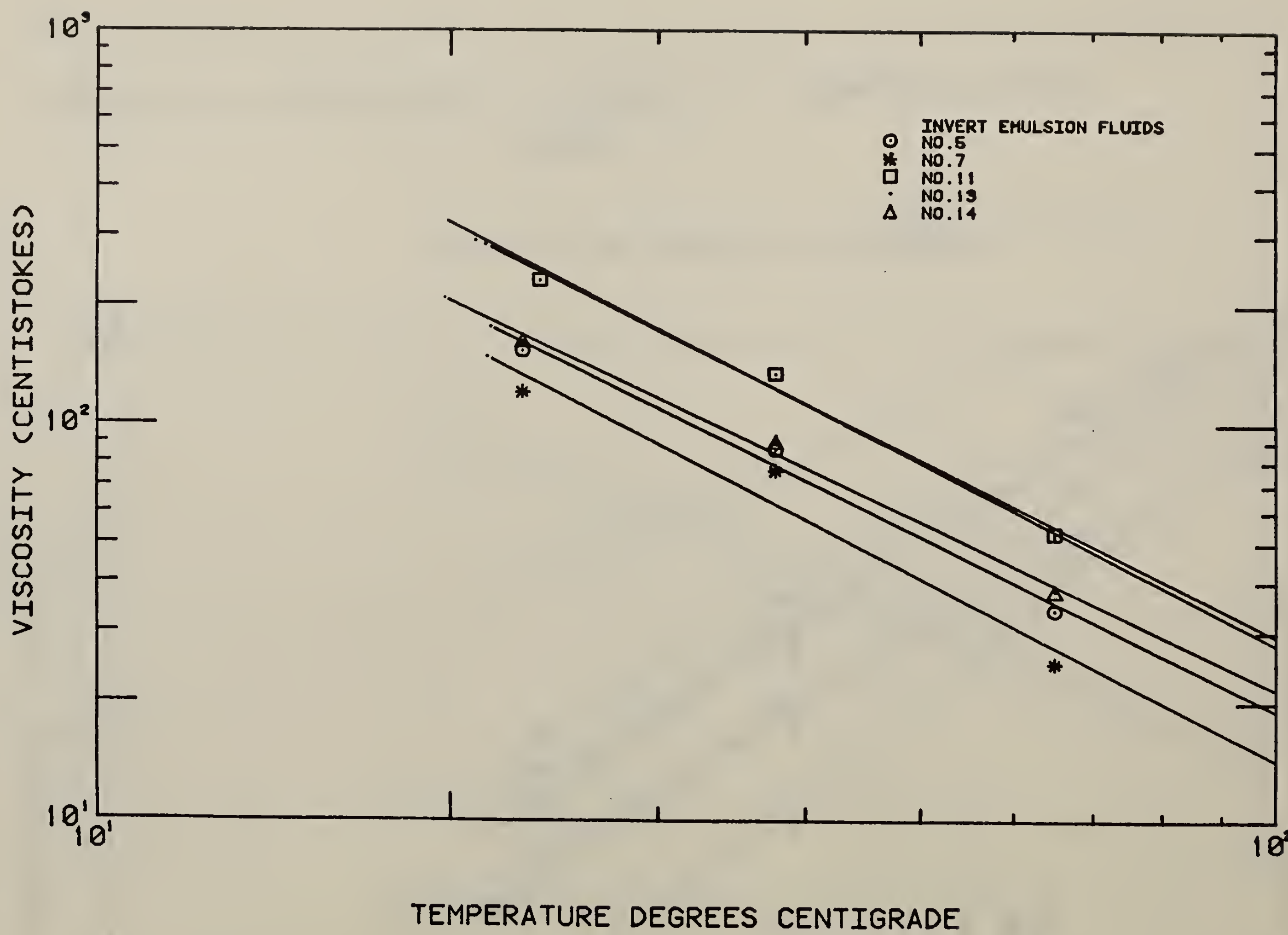

FIGURE 12

EFFECT OF TEMPERATURE ON VISCOSITY OF HYDRAULIC FLUIDS

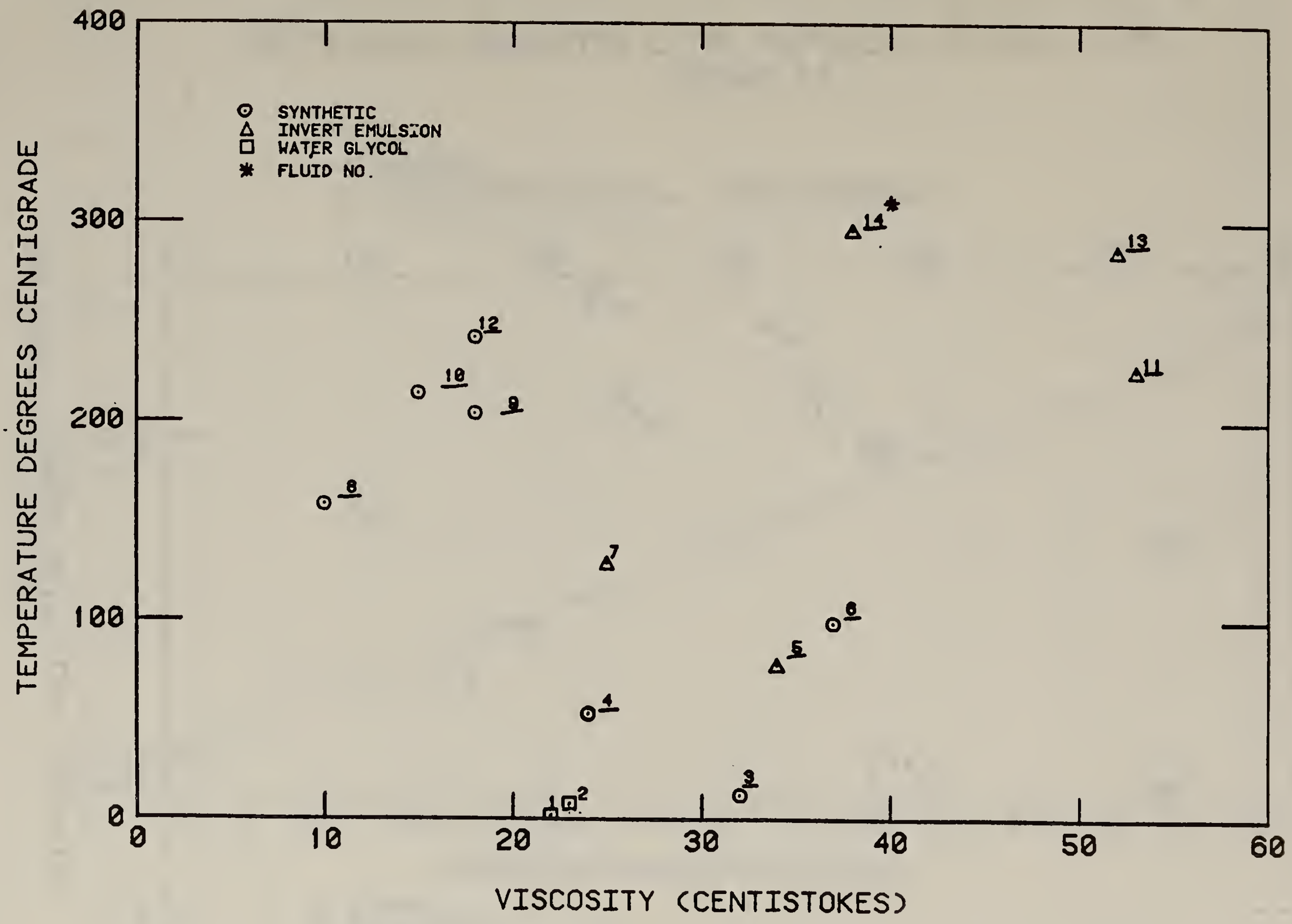

FIGURE 13

RELATION OF HYDRAULIC FLUID VISCOSITY TO EXHAUST TEMPERATURE

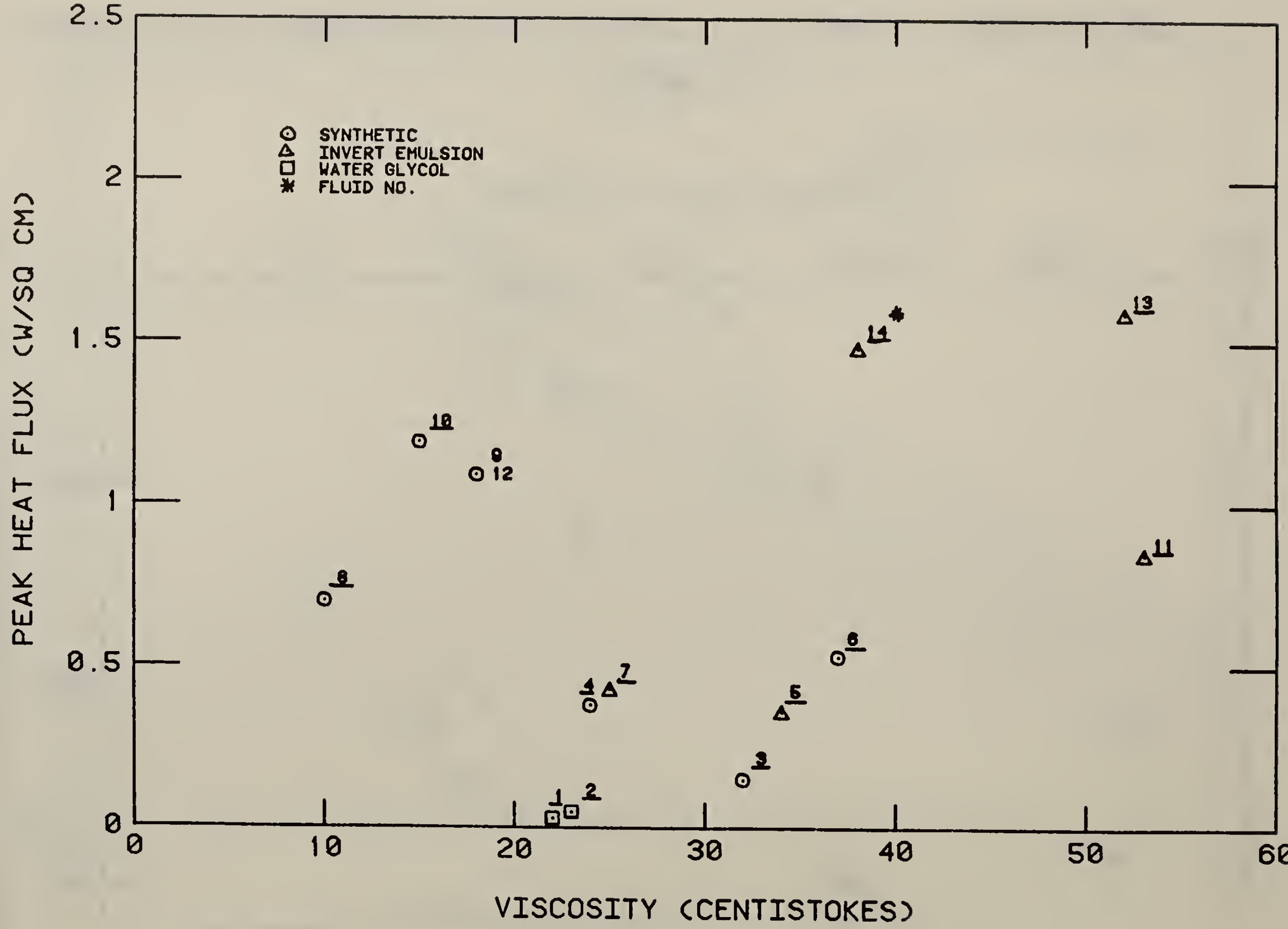

FIGURE 14
RELATION OF HYDRAULIC FLUID VISCOSITY TO HEAT FLUX

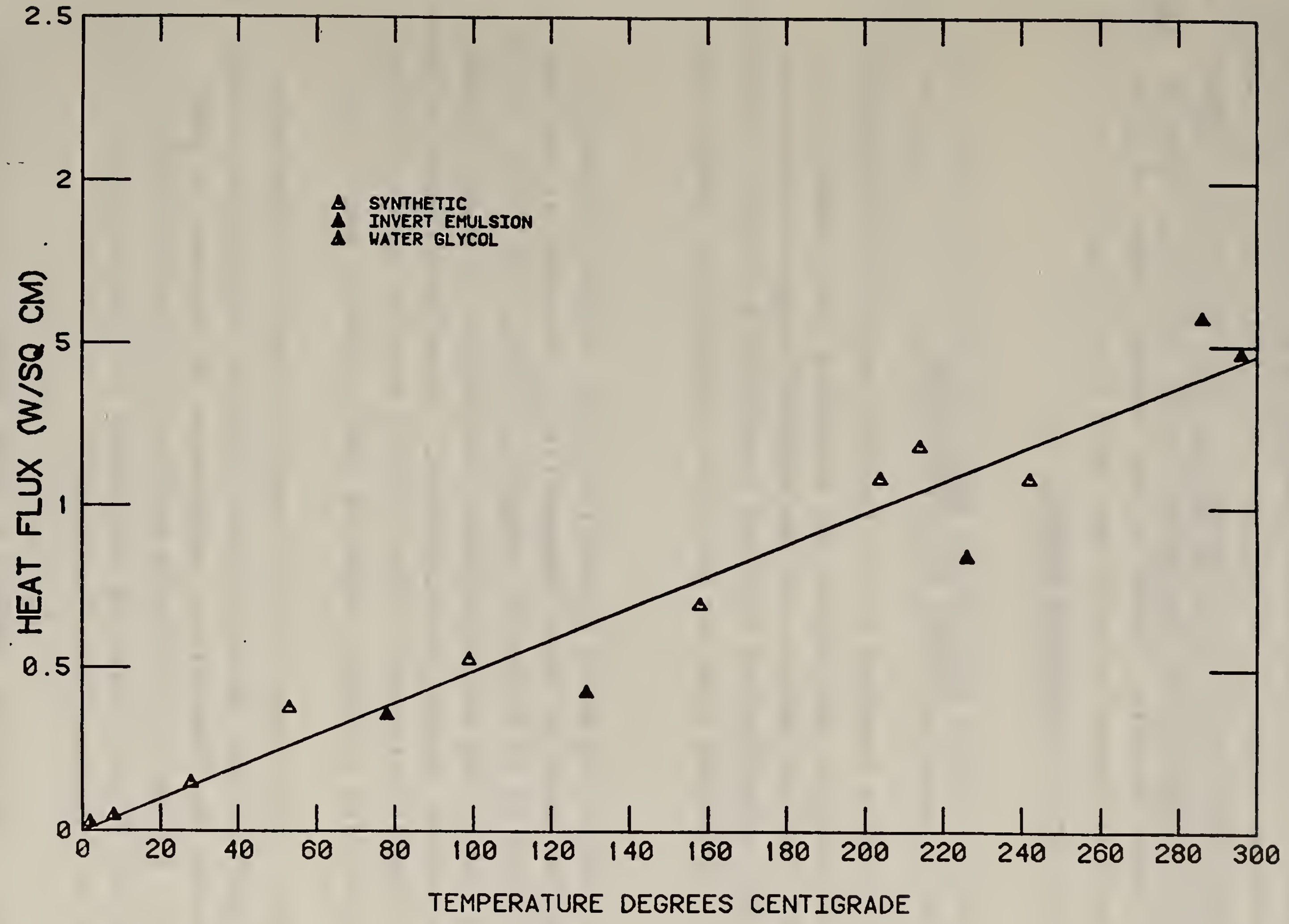

FIGURE 15

RELATION OF HEAT FLUX TO EXHAUST TEMPERATURE that either measurement could be used to characterize the flammability of the hydraulic fluids tested.

Considering the 10 second temperature rise and heat flux data (listed in table 2) it appears that, with the exception of the water glycols, fluids in the viscosity range of 20-38 centistokes reached no more than 26 percent of their peak temperature values in 10 seconds. The remaining fluids exceeded 50 percent of their peak values in 10 seconds. The relationship between peak heat flux and the 10 second heat flux value is not obvious. Generally with the exclusion of water glycols, fluids in the viscosity range of 10-20 and 38-60 centistokes were closer to their peak heat flux values at 10 seconds than fluids in the 20-30 centistokes range.

7. SUMMARY AND CONCLUSIONS

The Center for Fire Research at the National Bureau of Standards has developed a spray ignition test method for measuring the flammability of hydraulic fluids. The new method uses the MSHA/CFR Temperature-Pressure Spray Ignition Test apparatus and includes provisions for making quantitative measurements of temperature rise and heat flux generated by flaming fluid sprays.

The method, instead of being a pass-fail test, allows a means for rank ordering fluids based on their flammability performance in the test. For example, in tests on 14 different hydraulic fluids, six of the fluids might be rated as high heat potential materials because of measured peak temperature rise values ranging from 204-296°C. Five fluids might be rated as moderately flammable with peak values ranging from 59-158°C and three might be considered fire resistant based on peak values of only 2-12°C.

For comparison, the Center for Fire Research used the Temperature-Pressure Spray Ignition Test Method (Code of Federal Regulations Schedule 30 Part 35) to evaluate the flammability performance of the same 14 test hydraulic fluids. Eleven of the fluids would be rated unacceptable by the (CFR/MSHA) test criteria and three of the fluids (two water glycols and one synthetic) would be considered fire resistant.

A significant relationship appears to exist between hydraulic fluid viscosity and flammability. It was found that:

- Flammability generally appears to increase with increasing fluid viscosity for the invert emulsion fluids.

- Flammability generally appears to decrease with increasing fluid viscosity for synthetic fluids.

- There may be no relationship between viscosity/flammability for water glycol fluids. These fluids did not ignite at the lower viscosity range tested.

8. ACKNOWLEDGMENTS

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5. AUTHOR(S)

Joseph J. Loftus, Nilsa Juarez, Adalberto Maldonado, and Jeffrey Simenauer

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This report describes a spray ignition flammability test procedure which was developed and designed to be used as an alternative to the spray ignition test used by the Mine Safety and Health Administration (MSHA) to qualify hydraulic fluids for use in underground coal mines. The test procedure allows for quantitative measurement of heat and energy developed by fluids which may ignite in the test and provides for rank ordering of fluids according to their flammability. The testing program included currently used fluids such as invert emulsions, synthetics, and water glycols. Studies showed that the water glycol fluids were the only fluid type to resist ignition by spray testing. All other fluid types were ignited and in some cases produced considerable flaming.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Flammability; heat flux; pressure; spray ignition; temperature rise.

13. AVAILABILITY

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