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Study of Fire Extinguishment of a Replacement Fluid For Use In Transformers In Lieu of Askarel

Office of Research and Development
Washington, DC 20590

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16. Abstract

A series of tests were performed at the Factory Mutual Test Center 1) to obtain information on the performance of various extinguishing agents used with hand-held fire extinguishers to control fire involving a Midel,® a transformer fluid for replacement of Askarel, and 2) to compare the results with those obtained in a previous test series involving two other replacement transformer fluids. The tests were designed to simulate the ignition and development of a pool fire which might follow accidental transformer case rupture. The extinguishing agents and dispensing hardware selected were those that might conceivably be carried on board vehicles or, in the case of water spray, might be available from local fire departments. Laboratory tests were performed on the Midel fluid to determine 1) flash and fire points, 2) time of piloted ignition, 3) pyrolysis rate, 4) convective and radiative heat release rates, and 5) gaseous product generation rates.

Purple K dry powder appeared to be the best extinguishant for use on Midel spill fires. Of three Askarel replacement transformer fluids evaluated in this and the previous tests Midel appeared to burn the most violently.

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Preface

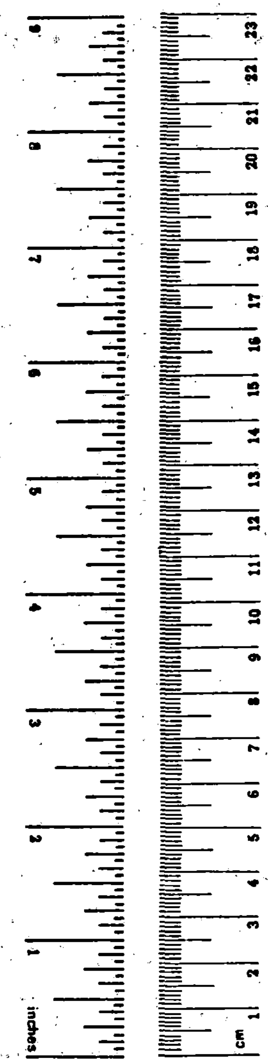
The work described in this report was performed at the Factory Mutual Research Corporation under contract to the Department of Transportation, Transportation Systems Center, Mr. I. Litant, technical monitor. The program was sponsored by the Federal Railroad Administration, Office of Research and Development, and directed by M. Clifford Gannett, Chief of the Passenger Equipment Division. The purpose of this study was to evaluate the effectiveness of common fire extinguishing agents on MIDEL, a transformer cooling fluid, and to determine the flammability characteristics of the MIDEL fluid.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

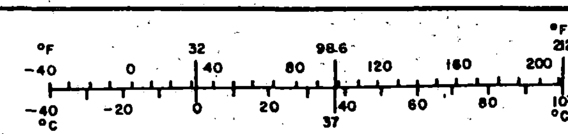
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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I. INTRODUCTION

Transformer fluids containing Askarel, a substance of extremely low flammability, are, nevertheless, a highly toxic hazard to the environment when spilled or when released through rupture of the transformer case. Various replacement fluids have been developed and, while less toxic, they are flammable. Factory Mutual Research Corporation (FMRC) under contract to DOT* has performed extinguishment tests on Dow Corning 561® silicone transformer fluid, and on RTemp® fluid manufactured by RTE Corporation. The present project was designed to compare another transformer fluid, Midel, with those previously tested using the same size pan fire, methods of extinguishment, and trained firefighter. Extinguishing agents used in this as well as in the previous mentioned contract were CO_2, Halon 1211, Halon 1301, Aqueous Film-Forming Foam, Purple K dry powder, and a fine water spray. Evaluation of the results indicates that Halon extinguishants were extremely effective in extinguishing the Midel Fluid in still air. However, under potentially windy field conditions, the effectiveness of Halon would be greatly reduced. Based upon test results and an evaluation of expected field environmental conditions, it is the author's opinion that Purple K dry powder would be the best choice.

Additional laboratory testing was performed on the Midel fluid to determine: 1) flash and fire points, 2) time of piloted ignition as a function of heat flux to the liquid surface as well as the minimum heat flux required to produce ignition, 3) pyrolysis rates ($gm/m.^2/s$) as a function of heat flux to the liquid surface, 4) convective and radiative heat release rates as a function of the heat flux to the liquid surface and mass fracton of oxygen in the atmosphere (Heat fluxes up to 6 $Watts/cm^2$ were used.),5) generation rates of gaseous products.

A sixth task was to supply available comparable data for items 1) through 5) for other liquids and solids.

Variations in extinguishing methods and times to knock down a fire were noted when the same trained operator was unable to duplicate the extinguishment with CO_2 of two identical fires. This was due to variations in agent

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* Heard, D.B., "Study of Fire Extinguishment of Transformer Fluids," DOT Order No. DTRS-57-80-P-80576, FMRC Report J.I. OFON1.RG (RC80-T-59), July 1980.

direction, distance to the flame, and other human factors which manifest themselves differently for each fire test.

A discussion of the properties of Midel and the laboratory test results are presented in Appendix A.

A video tape record of the extinguishment tests conducted in this program is furnished as part of this report.

II. FIRE TEST PROCEDURE

This series of Fire Extinguishment Tests was performed on July 2, 1981 at the Factory Mutual Test Center in West Glocester, R.I. The fluid tested was Midel, manufactured by Sterling Division of Reichhold Chemicals, Inc., Sewickley, Pennsylvania 15143. This fluid was delivered in a 55-gal steel drum weighing 520 lb. This material is of a dark amber color, resembles a viscous motor oil, and is very slippery.

The series of six tests was conducted, using the following agents and extinguishers (Figure 1):

Test 1 - Carbon dioxide, Kidde 15 lb extinguisher;

Test 2 - Halon 1211®, Ansul SY0541 extinguisher;

Test 3 - Halon 1301®, extinguisher by Metalcraft, Inc., 2-3/4-lb military unit.

Test 4 - Fine water spray; Akron Brass, variable pattern spray nozzle on 1-1/2 in. hose at 120 psi;

Test 5 - Aqueous Film Forming Foam - Light Water®, 3M extinguisher Model PE25;

Test 6 - A dry-powder extinguishment - Purple K - manufactured by Badger-Powhatan, Ansul extinguisher Model SY-1023.

For each test, approximately 1/2-in. transformer replacement fluid (4 gal) (15.14 ℓ) was floated on top of water filling a 4-ft (1.22-m) diameter pan to approximately 1/2 in. from the rim. Midel ignition was obtained by spreading approximately 1 to 2 quarts (1 to 2 ℓ) of heptane over the transformer fluid, since the Midel could <u>not</u> be ignited using a propane torch. The heptane was lighted and burned vigorously for 2 or 3 min, igniting the transformer fluid,

After exhausting the heptane, and when the Midel reached a steady state of burning, the extinguishing agent was applied by a well trained fire-

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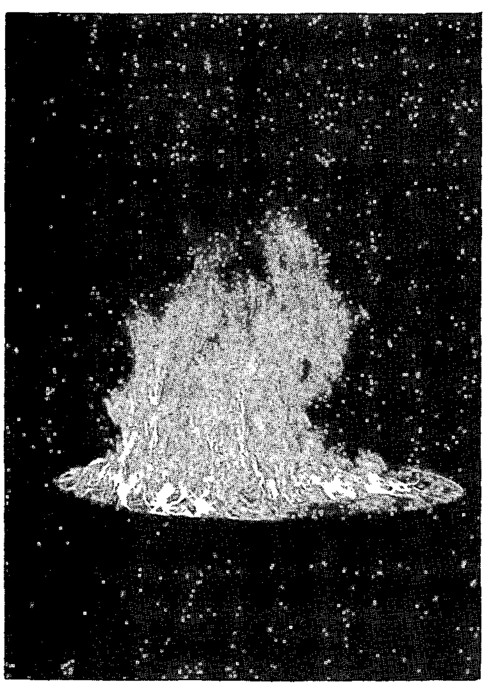
FIGURE 1 FIRE EXTINGUISHERS USED IN TESTS (left to right: CO_2; AFFF (Light Water); Dry Powder (Purple K); Halon 1211; Halon 1301)



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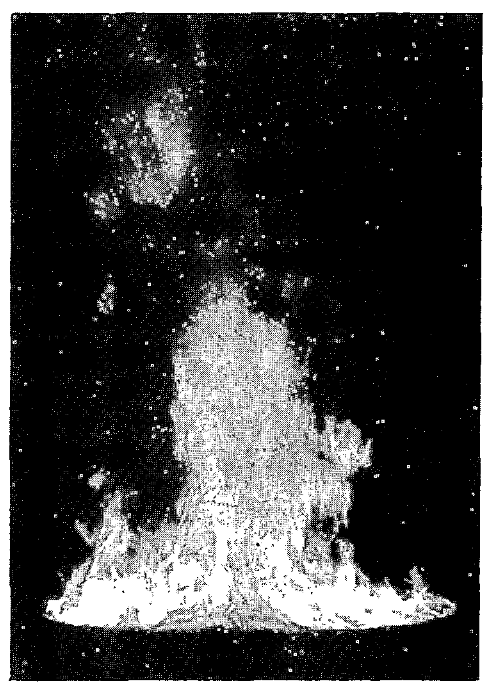

3783-3

FIGURE 2 IGNITION USING HEPTANE

FIGURE 3 MIDEL FLUID FREEBURN

fighter. Every test was performed by the same firefighter to minimize differences in technique.

The flames of the burning heptane were about 4 ft high (Figure 2) but, when the heptane had burned off after approximately 2-1/2 min and the Midel Fluid had reached a steady-state freeburn, flames occasionally reached 12 to 15 ft (Figure 3). The Midel burned vigorously giving off a light gray smoke and a faint vegetable oil smell accompanied by crackling and popping sounds. At 4 min the flames were approximately 7 ft high. At 5 min the flames were 9 ft high. A small eruption or steam explosion occurred at 5 min 30 s throwing a small amount of burning fuel out of the pan. At 6 min the flames appeared to be 8 ft high and at 10 min the flames were approximately 9 ft.

During all tests the free-burning Midel fluid flames appeared to average between 7 and 10 ft high, but at times reached approximately 15 ft.

The numbering of the Extinguishing Tests in this report does not follow the numbering of the tests shown in the video tape. The test sequence shown in the report is made to coincide with the series of tests performed on Dow Fluid 561 and on RTemp so that direct comparisons can be made.

III. TEST RESULTS

3.1 TEST 1

AGENT: CO_2

EXTINGUISHER: KIDDE 15 lb

When the CO_2 agent struck the burning Midel, a large flareup occurred (approximately 15 ft high).

Extinguishment was accomplished in approximately 1-1/2 seconds.

3.2 TEST 2

AGENT: HALON 1211

EXTINGUISHER: ANSUL Model SY0541

When the Halon 1211 was applied to the burning Midel a small amount of flareup occurred (approximately 2 to 3 ft high).

Extinguishment was accomplished in approximately 5-1/2 seconds.

(Figure 5)

3.3 TEST 3

AGENT: HALON 1301

EXTINGUISHER: METALCRAFT (2-3/4 lb MILITARY UNIT)

There was no flareup when the Halon 1301 was applied to the burning Midel.

Extinguishment was accomplished in 2 seconds. (Figure 6)

3.4 TEST 4

AGENT: FINE WATER SPRAY

EXTINGUISHER: 1½" HOSE LINE WITH AKRON BRASS VARIABLE PATTERN NOZZLE

When the water spray was applied to the burning Midel, a large flareup (approximately 15 to 19 ft high) occurred with a resultant flame spread.

Extinguishment occurred in 13-1/2 s. (Figure 7)

3.5 TEST 5

AGENT: AQUEOUS FILM FORMING FOAM (AFFF)

EXTINGUISHER: 3M MODEL PE 25

When the AFFF was applied to the burning Midel a large flareup (approximately 15 ft high) was produced resulting in some flame spread.

Extinguishment occurred in 8 s. (Figure 8)

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FIGURE 4 CO_2 EXTINGUISHMENT

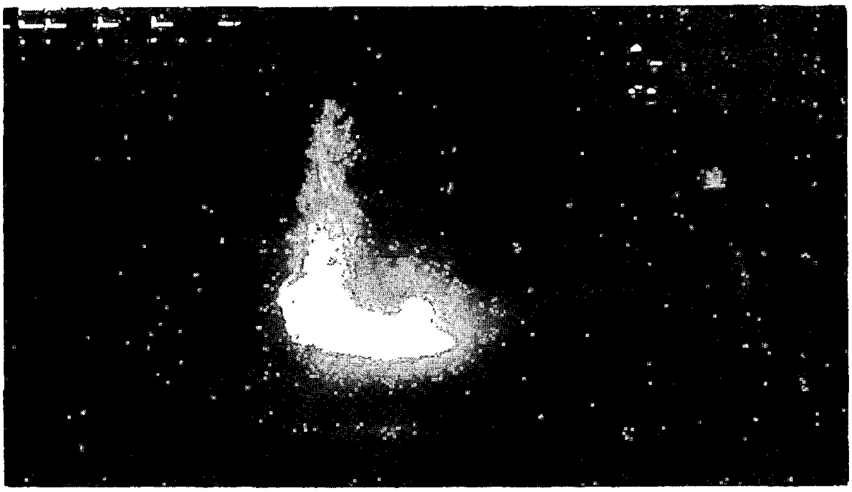

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FIGURE 5 HALON 1211 EXTINGUISHMENT

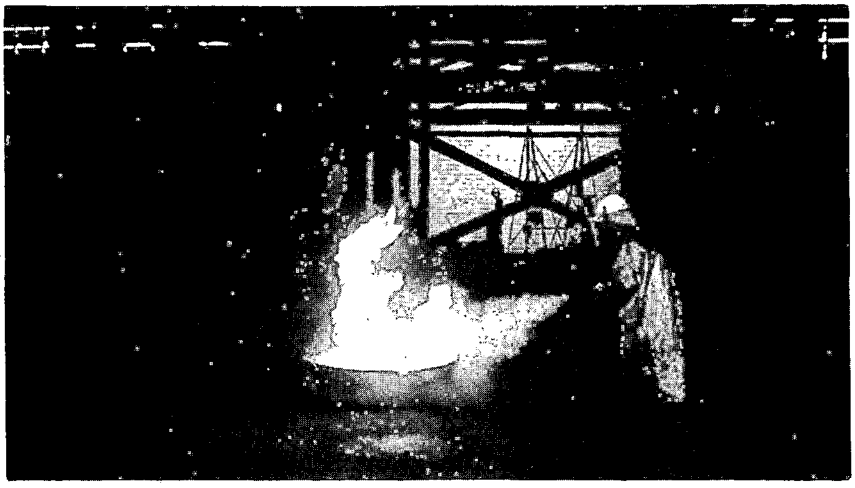

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FIGURE 6 HALON 1301 EXTINGUISHMENT

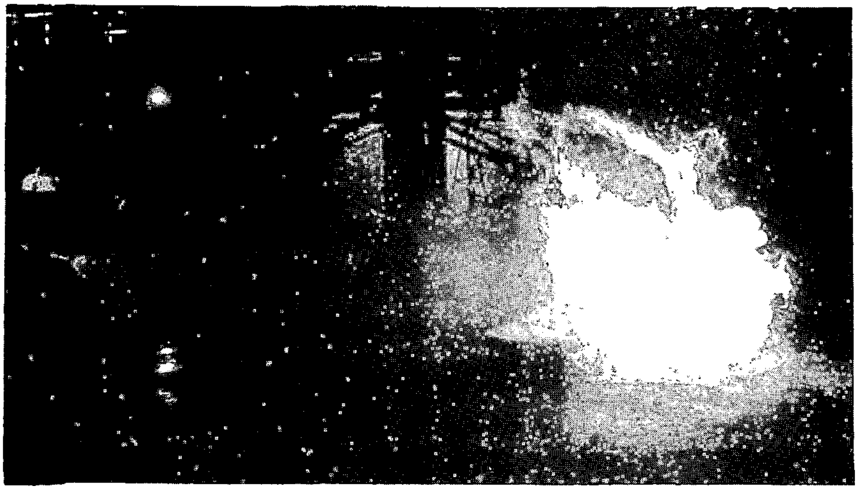

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FIGURE 7 WATER SPRAY EXTINGUISHMENT

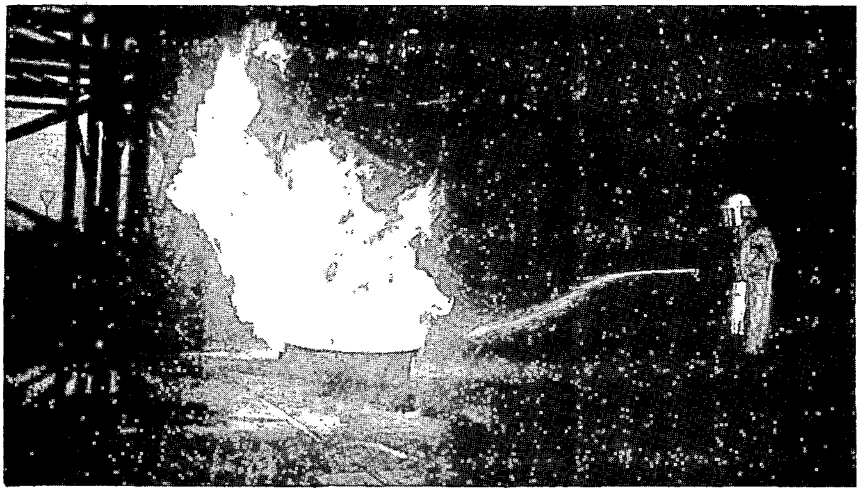

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FIGURE 8 AFFF (LIGHT WATER) EXTINGUISHMENT

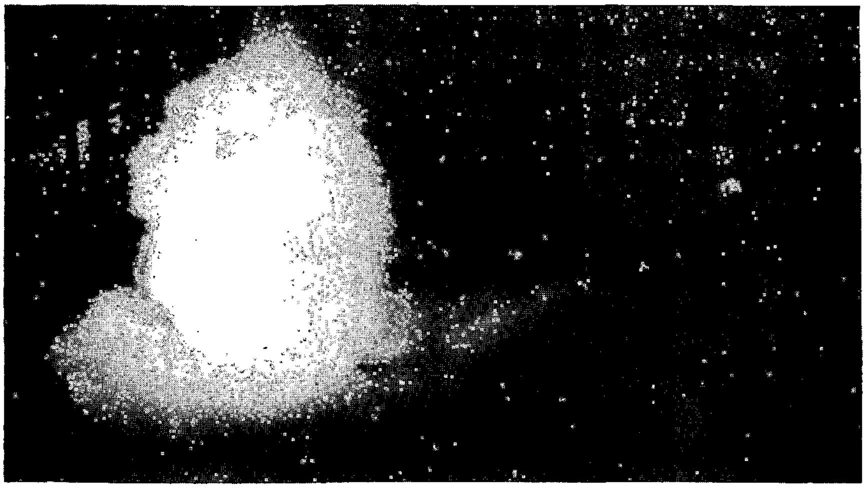

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FIGURE 9 DRY POWDER (PURPLE K) EXTINGUISHMENT

3.6 TEST 6

AGENT: DRY CHEMICAL (PURPLE K) POWDER;

EXTINGUISHER: ANSUL MODEL SY-1023

When the dry chemical was applied to the burning Midel a moderate flareup occurred (approximately 5 to 6 ft high) resulting in some flame spread. Extinguishment occurred in 6-1/2 s. (Figure 9)

3.7 TEST 1a - REPEAT OF TEST 1

AGENT: CO_2

EXTINGUISHER: KIDDE 15 lb.

This test was repeated to photograph the extinguishment. The CO_2 extinguished the flames in 6 s. The variation in time compared with Test 1 may have been caused by two factors: 1) the CO_2 during the second test was discharged onto the floor prior to impinging on the flaming liquid; and 2) the pan being filled to the brim, some of the burning fuel was "blown" out of the pan into a shielded position requiring more time to complete extinguishment. The flareup during the application of the extinguishant in this test appeared to be approximately 12 ft high. (Figure 4)

IV. SUMMARY AND CONCLUSIONS

The results of this test series using Midel Fluid together with those of the previous test series using RTemp and Dow Corning, 561 transformer fluids have permitted comparison of the relative effectiveness of the transformer fluid pool fire extinguishment employing an assortment of agents and hand-held portable fire extinguishers. The portable fire extinguishers are typical of the types which might be carried on electrical railroad prime movers, and the water spray is of a type that would be available within the jurisdiction of fire departments in populated areas. Table I presents a summary of the individual extinguishment tests. Table II is a summary evaluation of the performance and characteristics of extinguishing systems used in this program. The "fastest" extinguishment was accomplished by Halon 1301 using the most compact hardware of the test. It is felt that wind conditions would degrade the effectiveness of this agent and other gaseous extinguishants.

The water-based extinguishing agents, (fine water spray and AFFF) in addition to producing a characteristic flareup when applied to burning transformer oil, are both questionable for use on electrical fires and, therefore, cannot be recommended. The fine water spray is also reliant on a pressurized water supply which is not always readily available. AFFF agent could freeze, making it unreliable for outdoor use, unless proper means are taken to depress its freezing point to the desired level for the expected environment. The halon extinguishants, while extinguishing the test fires rapidly and with little flareup, are not appropriate for a windy, outdoor environment.

Purple K dry powder extinguishant appears to be the best type for use on the Midel spill fires, even though it was not the fastest and produced a flare when initially contacting the burning fuel. Dry powder extinguishants do not freeze, prevent reignition by blanketing the fuel surface and are readily available. On the negative side, dry powder extinguishers have been known to cake and become inoperative due to the intrusion of moisture into the extinguisher.

Of the three Askarel replacement transformer fluids tested, Dow Corning 561 burned with the least intensity and Midel burned most intensely.

The variation in extinguishment time cannot be used to rank the merits of an extinguishment. Time variations occur with the method of application of

TABLE I

EXTINGUISHING TEST SUMMARY

OF MIDEL TRANSFORMER FLUID

Midel Test No.	Extinguishing Agent	Extinguisher	Extinguishing Time (sec)	Comments
1	CO_2	15 lb Walter Kidde	1-1/2	Large flareup.
2	Halon 1211	5 lb Ansul 54-0541	5-1/2	Some flareup.
3	Halon 1301	2-3/4 lb Metalcraft	2	No appreciable flareup.
4	Water Spray	1-1/2 in. Hose Line with Spray Nozzle	15	Large flareup as is typical with water spray on flammable liquids.
5	AFFF	2-1/2 gal "Light Water" 3M Co.	8	Large flareup. Extinguishant may freeze.
6	Dry Powder (Purple K)	10 lb Ansul SY-1023 Badger Purple K	6-1/2	Leaves residue. Less affected by wind than the gaseous extinguishers. Moderate flareup and some spreading of flames.
1a	CO_2	15 lb Walter Kidde	6	Repeat of Test 1. Slower time due to spill and shielding by pan. Large flareup.

TABLE II

PERFORMANCE EVALUATION OF EXTINGUISHING SYSTEMS

Agent	Effective Extinguishment for Midel Fluid	Comments
CO_2	Excellent	Fast Fire Suppression. Flareup and spread of fire. Subject to wind condition.
Halon 1211	Good	May not cool sufficiently. Subject to wind condition.
Halon 1301	Excellent	Fast Fire Suppression. May not cool. Subject to wind condition. Package is small and light - easy to handle.
Water Spray	Fair	Subject to freezing. Produced flareup. Needs pressurized water supply. Questionable for electric fires.
AFFF	Good	Subject to freezing unless provided with antifreeze. Produced flareup. Questionable for electrical fires. Leaves residue.
Purple K	Good	Leaves residue. Some flareup and little spread of flame.

the agent, local conditions, location of the fire, and also may vary markedly with the same operator when knocking down similar fires.

APPENDIX A

FIRE PROPERTIES OF MIDEL TRANSFORMER FLUID

by

Archibald Tewarson

A.1 INTRODUCTION

The fire properties of Midel transformer fluids were measured using the Factory Mutual Small-Scale Combustibility Apparatus shown in Figure A-1. The procedures used were the same as in the previous study for dimethyl-siloxane and hydrocarbon transformer fluids[(1)].

A.1.1 Sample Size, Container, Air Flow Rate And External Heat Flux Used In The Tests

In each test 50 ml of Midel sample were used inside an aluminum container, about 0.007 m^2 in area and about 0.02 m deep. Air flow rate was about 1.4×10^{-3} m^3/s. Three external heat flux values were used. (For other experimental details see Reference 1.)

A.1.2 Types Of Measurements

The following measurements were made in the tests:

1) Flash and fire point using the "Cleveland open cup" method;
2) time to piloted ignition as a function of external heat flux;
3) mass loss rate in pyrolysis as a function of external heat flux; and
4) heat release rate and product generation rates.

A.2 EXPERIMENTAL RESULTS

A.2.1 Flash And Fire Point

Flash and fire point data for Midel are listed in Table A.1, which also includes data for dimethyl-siloxane and hydrocarbon fluids, measured in the previous study[(1)].

A.2.2 Piloted Ignition

The data for time to piloted ignition as a function of external heat flux for Midel are listed in Table A.2; data for dimethyl-siloxane and hydrocarbon fluids, taken from Reference 1, are also included.

From the data in Table A.2, the total energy supplied to the fuel for ignition, (E_T) can be calculated which is equal to the product of ignition time and external heat flux[(1)]. The smaller the value of E_T, the easier is the ignition and the faster the expected surface flame spread. Thus, $1/E_T$ can be

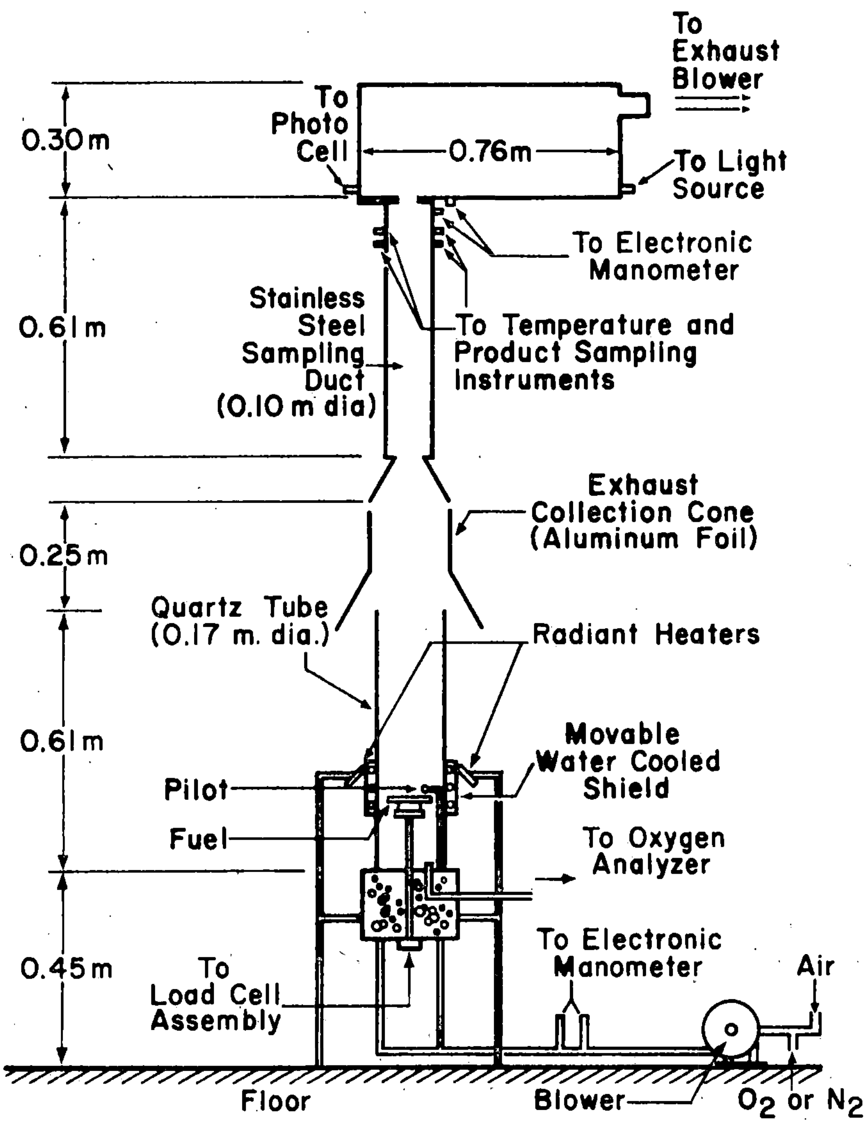

FIGURE A-1 Factory Mutual Small-Scale Combustibility Apparatus

TABLE A.1

FLASH AND FIRE POINT OF TRANSFORMER FLUIDS[a]

Fluid	Flash Point (°C)	Fire Point (°C)
Midel	257	307
Dimethyl-siloxane	310[b]	374[b]
Hydrocarbon	282[b]	313[b]

[a] Measured by using "Cleveland Open Cup" method (ASTM D-92)

[b] From Reference 1

TABLE A.2

TIME TO PILOTED IGNITION IN SECONDS FOR TRANSFORMER FLUIDS[a]

External Flux (kW/m^2)	Fluids		
	Midel	Dimethyl-siloxane[b]	Hydrocarbon[b]
26	380.0	921	384.3
31	-	-	257.8
37	196.7	266.9	181.2
46	142.5	197.7	138.3
52	122.4	152.9	-
60	-	128.0	-
71	-	102.3	-

[a] forced air flow ($\sim 1.4 \times 10^{-3}$ m^3/s); sample = 5×10^{-3} m^3 in aluminum dish ~ 0.007 m^2 in area and ~ 0.02 m deep.

[b] data taken from Reference 1

used directly to compare the fluids on a relative basis for expected ignition/surface flame spread characteristics; $1/E_T$ was defined as the ignition/surface flame spread parameter in the previous study[1]. Table A.3 lists the relative values of $1/E_T$ for Midel using red oak as a reference. (The reference corresponds to arbitrarily setting 100 as the value of $1/E_T$ for red oak at an external heat flux value of 31 kW/m^2, very similar to the previous study[1].) The data for dimethyl-siloxane and hydrocarbon fluids, taken from Reference 1, are also included in the table.

The higher the value of the relative ignition/surface flame spread parameter in Table A.3, the easier is the ignition and the faster the expected surface flame spread. The data in Table A.3, thus, indicate that the expected rate with which surface flame spread would occur would be similar for the Midel and hydrocarbon fluids and would be faster than for dimethyl-siloxane. Further, the magnitude of critical flux at or below which ignition and flame spread is not expected to occur can also be estimated (see Section A.2.3 for the magnitudes of the critical flux).

A.2.3 Generation Rate Of Combustible Vapors

The generation rate of combustible vapor is expressed in terms of mass loss rate per unit sample surface area (g/m^2s).

Pyrolysis

The mass loss rate for pyrolysis was measured under nitrogen environment. The average data for Midel, for steady-state conditions, are listed in Table A.4, which also includes data for dimethyl-siloxane and hydrocarbon fluids, taken from Reference 1.

The data in Table A.4 indicate that the rate of generation of combustible vapors for the three transformer fluids will be dimethyl-siloxane > hydrocarbon > Midel, which is related to the effective heat of gasification and surface reradiation loss. The calculated data for effective heat of gasification and surface reradiation loss are listed in Table A.5

Surface reradiation has been found to be very close to the critical heat flux at or below which ignition and surface flame spread is not expected to occur[2]. The data for surface reradiation in Table A.5, thus, can be used as representative values of critical heat flux. In the table dimethyl-siloxane has

TABLE A.3

RELATIVE MAGNITUDES OF IGNITION/SURFACE FLAME SPREAD PARAMETER FOR TRANSFORMER FLUIDS RELATIVE TO RED OAK[a]

External Flux (kW/m^2)	Red oak[b]	Midel	Dimethyl-siloxane[b]	Hydrocarbon[b]
26	-	63	26	62
31	100	-	-	78
37	203	86	63	92
46	329	95	68	97
52	339	98	78	103[c]
60	492	104[c]	81	108[c]
71	475	108[c]	85	113[c]

[a]Reference corresponds to arbitrarily setting the value of $1/E_T$ for red oak at an external heat flux value of 31 kW/m^2 to be equal to 100

[b]Data taken from Reference 1

[c]Estimated values

TABLE A.4

AVERAGE STEADY STATE MASS LOSS RATE PER UNIT SURFACE AREA ($g/m^2 s$) FOR THE PYROLYSIS OF TRANSFORMER FLUIDS IN A NITROGEN ENVIRONMENT

External Heat Flux (kW/m^2)	Fluids		
	Midel	Dimethyl-siloxane[a]	Hydrocarbon[a]
26	0.52	-	-
31	-	1.0[b]	-
37	9.4	1.6[b]	16.9
46	16.4	39.3[c]	39.1
52	21.0	70.9[c]	43.3
60	27.0	111.0[c]	57.3
71	-	159.0[c]	71.5

[a]Data taken from Reference 1

[b,c]Note the change in pyrolysis mechanism

TABLE A.5

EFFECTIVE HEAT OF GASIFICATION AND SURFACE RERADIATION LOSS FOR TRANSFORMER FLUIDS[a]

Fluid	Effective Heat of Gasification (kJ/g)	Surface Reradiation Loss (kW/m^2)
	-	22[d]
Dimethyl-siloxane[b,c]	0.21[e]	37[e]
Hydrocarbon[b]	0.61	25
Midel	1.28	25

[a]calculated from the data in Table A.4

[b]data taken from Reference 1

[c]dimethyl-siloxane exhibits two modes of pyrolysis, one for lower heat fluxes, and the other for higher heat fluxes

[d]corresponding to lower heat fluxes

[e]corresponding to higher heat fluxes

two values of critical flux, one for the lower heat fluxes and the other for the higher heat fluxes where the decomposition appears to be different than for the lower heat fluxes.

It is interesting to note that the heat of gasification of Midel (1.28 kJ/g), which is an oxygenated carbon hydrogen type of fluid, is very close to the value for methanol (1.21 kJ/g). The difference between methanol and Midel fluid in terms of generation of combustible vapors is the difference between the surface reradiation loss or critical heat flux, (0.75 kW/m^2 for methanol; 25 kW/m^2 for Midel fluid).

A.2.4 Heat Release Rate

The heat is released as a result of the combustion of fuel vapors in fires and is defined as the actual heat release rate. The actual heat release rate is calculated from the generation rates of CO and CO_2 or from the depletion rate of O_2[1,2]. The actual heat release rate has a convective and a radiative component defined as convective and radiative heat release rate respectively. The convective heat release rate is calculated from the measured data for total mass flow rate and gas temperature above ambient and using specific heat of air at the gas temperature[1,2]. The radiative heat release rate is calculated from the difference between actual and convective heat release rates.

The data for the ratio of heat release rate to mass loss rate or heat of combustion for Midel are listed in Table A.6, where data for the hydrocarbon fluids, taken from Reference 3, are also listed. (Data for dimethyl-siloxane cannot be used in this form, because the mass loss rate in combustion cannot be measured accurately due to surface crust formation.) The data in Table A.6 indicate that actual heat of combustion for Midel is comparable to the values for the hydrocarbon fluids; convective heat of combustion is somewhat lower and radiative heat of combustion is somewhat higher for Midel compared to other hydrocarbon fluids.

Knowing the heat of combustion, effective heat of gasification and surface reradiation loss, heat release rate can be calculated for various fire scenarios, if the flame heat flux to the fluid is known. Table A.7 lists the calculations for 52 kW/m^2 for Midel where, based on our previous research on C-H-O type of fluids, it is assumed that 52 kW/m^2 is a representative value of flame heat flux

TABLE A.6

DATA FOR HEAT OF COMBUSTION AND PRODUCT YIELDS

FOR MIDEL AND HYDROCARBON TRANSFORMER FLUIDS[a]

Fluid	Heat of Combustion (kJ/g)			Product Yield (g/g)	
	Actual	Convective	Radiative	CO_2	CO
Midel	34.7	18.6	16.1	2.33	0.094
Hydrocarbon Fluids[b]					
1	38.2	25.1	13.1	2.02	0.036
2	35.4	23.8	11.6	-	-
3	34.5	24.0	10.5	-	-
4	38.0	25.0	13.0	-	-
5	38.1	26.0	12.1	-	-

[a]Average data from several tests: Heat of Combustion = heat release rate/mass loss rate; Product Yield = product generation rate/mass loss rate

[b]Data taken from Reference 3

TABLE A.7

HEAT RELEASE RATE AND PRODUCT GENERATION RATES FOR TRANSFORMER FLUIDS

FOR LARGE POOL FIRES

Fluid	Heat Release Rate (kW/m^2)			Product Generation Rate (g/m^2s)	
	Actual	Convective	Radiative	CO_2	CO
Dimethyl-siloxane[a]	134	88	46	5.7	0.04
Midel[b]	730	390	340	49	2.0
Hydrocarbon Fluids[c]					
1	1060	700	360	57	1.0
2	1070	720	350	-	-
3	910	640	270	-	-
4	1080	710	370	-	-
5	1100	750	350	-	-

[a] Data taken from Reference 1

[b] Data calculated using data from Tables A.5 and A.6 for an external flux of 52 kW/m^2 (Note that experiments were not performed at 52 kW/m^2 for this fluid because of very high fire intensity expected at this flux. It is assumed that the heat release rate at 52 kW/m^2 is equal to the asymptotic value for large pool fires.)

[c] Data taken from Reference 3 for large pool fires where heat release rates reach their asymptotic value. Data are obtained by using the radiation scaling technique developed at Factory Mutual.

to the surface of Midel fluid for large pool fires. (In this study, the flame heat flux for large pool fires was not quantified using the radiation scaling technique developed for the FM small-scale apparatus.) Data for dimethyl-siloxane, taken from Reference 1, and hydrocarbon fluids from Reference 3 are also included in Table A.7 so that comparisons can be made between the fluids.

The data in Table A.7 indicate that heat release rate for Midel fluid is lower than the hydrocarbon fluids. The values for both fluids are considerably higher than for the dimethyl-siloxane fluid.

A.2.5 Product Generation Rates

The data for the yields of products are listed in Table A.6 for Midel and hydrocarbon fluid, where yield is defined as the ratio of product generation rate to mass loss rate. (For dimethyl-siloxane, the product yield cannot be calculated because mass loss rate in combustion cannot be calculated accurately due to surface crust formation.)

The yield of CO_2 for Midel and hydrocarbon fluid in Table A.6 are comparable. The yield of CO for Midel, however, is about three times the yield for the hydrocarbon fluid. Table A.7 provides data for the generation rates of CO and CO_2.

The data in Table A.7 indicate that generation rates of CO and CO_2 for Midel are smaller than for the hydrocarbon fluid but are considerably higher than the rates for dimethyl-siloxane fluid.

A.3 CONCLUSION

The data indicate that the fire hazard of the three transformer fluids due to ignition/surface flame spread, heat release rate, and generation rates of CO and CO_2 is expected to be on the order hydrocarbon $\gtrsim$ Midel > dimethyl-siloxane fluid.

The data have been presented in a fashion such that fire properties of the fluid can be estimated for various fire scenarios in which heat flux received by the fluid is known. It should be noted that flame heat flux to the surface of the Midel fluid for large pool fires needs to be quantified using the FM radiation scaling technique, for reliable comparisons with other fluids.

REFERENCES FOR APPENDIX A

1. Tewarson, A., Lee, J.L., and Pion, R.F., "Fire Behavior of Transformer Dielectric Insulating Fluids," U.S. Department of Transportation, Transportation Systems Center, Cambridge, Mass., Report No. DOT-TSC-1703, (National Technical Information Service, Springfield, Va., 22161), September 1979.
2. Tewarson, A., "Physico-Chemical and Combustion/Pyrolysis Properties of Polymeric Materials," U.S. National Bureau of Standards, Washington, D.C., Report NBS-GCR-80-295, (National Technical Information Service, Springfield, Va., 22161), November 1980.
3. Tewarson, A., "Combustibility Evaluations Using FM Small-, Intermediate-, And Large-Scale Combustibility Apparatuses," Factory Mutual Research Corporation Technical Report, FMRC J.I. 1A7E4.RC (to be issued).

APPENDIX B

REPORT OF NEW TECHNOLOGY

A review of the work performed under this contract discloses no new invention or discovery. However, a great deal of new data was generated concerning the flammability characteristics of the transformer coolant fluid, MODEL.