Methods of Testing Small Fire Extinguishers

United States Department of Commerce

National Bureau of Standards

Building Materials and Structures Report 150

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Methods of Testing Small Fire Extinguishers

H. Shoub, T. G. Lee, and J. M. Cameron

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A study has been made of methods of testing small hand-portable fire extinguishers considered suitable for application to flammable liquids. The study was performed by evaluating the effectiveness of the extinguishers, in which 5 different extinguishing agents were used on 10 types of fires, selected either because they had been used in standard extinguisher tests or simulated other possible conditions of hazard. An analysis was made of the relative merit of the fires for extinguisher testing, the effect of ambient variables on the tests, and the value of the several extinguisher types for use on the fires.

1. Introduction

Although several types of small hand-portable fire extinguishers have been available for combatting fires of flammable liquids, the relative efficiency of these devices has been little understood. The continuing work of the National Bureau of Standards has led inevitably to the conclusion that wide variations in performance were obtained with these devices. To determine a means for measuring the extent of these variations, a program of tests was undertaken under the sponsorship of the U. S. Coast Guard. While the primary purpose was to establish some standard of suitability of extinguishers for use on small motorcraft, it is considered that the work was of sufficiently broad aspect to allow extension of the applicability of the findings to many types of small flammable liquid fires.

In planning the tests, the program was envisaged in several parts. A group of fire extinguishers was selected to apply the extinguishing agents used in the study. Each device was representative of its type and class, and individually without defects that could impair its performance. A series of suitable fires were selected or devised. These included several types of test fires used by commercial testing agencies and the National Bureau of Standards. Additional types, making for a total of 10, were based on preliminary designs of the Merchant Marine Technical and Testing and Development Divisions of the Coast Guard. Finally, the effect of ambient variables on the tests was noted. Statistical methods were used in planning the tests and in analyzing the large body of data resulting from the program.

2. Description of Test Extinguishers and Agents

Fifteen extinguishers, all readily obtainable commercial makes, were chosen for the purposes of these tests. Each carried the Underwriters' Laboratories, Inc. B–2 rating. Among these were devices using all common types of extinguishing agents suitable for flammable-liquid fires, and further varied in capacity, and in rate, duration, range, and continuity of discharge. At the end of the program no wear or damage to the devices sufficient to affect their operating efficiency in any way was found. The extinguishers used are listed in table 1.

The extinguishers used may be classified into 4 groups according to the type of agent employed: vaporizing liquid, carbon dioxide, dry chemical, and foam. Of the 8 devices using vaporizing liquid, 7 were charged with carbon tetrachloride extinguisher fluid and 1 with chlorobromomethane. Of these, 4 were hand pumps; the remainder depended on gas pressure stored in the charge chamber to give the necessary expelling force. The carbon tetrachloride was supplied under the requirements of the Federal specification for this material. The single chlorobromomethane device was charged with fluid stated to comply with U. S. Air Force requirements. Two of the hand-pump extinguishers had a slightly intermittent action, and were the only ones in which the discharge rate was under the control of the operator. Because of differences in the mechanism, two of each size of hand-pump carbon tetrachloride extinguishers were included.

The three carbon dioxide type extinguishers each had different capacities: 2½, 5, and 10 lb. They were charged from standard CO_2 cylinders. The gas pressure in a fully charged device of any size is about 850 lb/in ^{2} at 70°F. Approximately 75 percent by weight of the discharge is effective for fire extinguishment.

Two of the three extinguishers in the dry-chemical group were of the stored-pressure type, and consisted of 4- and 5-lb devices. The third had its expelling gas in the form of a cartridge, and was of 4-lb capacity. Although all the dry chemicals consisted of finely ground bicarbonate of soda treated with a water repellent, only material manufactured for the particular extinguisher was used in each case.

A single extinguisher was of the foam type. It had 1¼-gal capacity, and was the only device of the 15 tested that was rated for use on ordinary combustible materials, as well as on flammable liquids. Also, it was not suited for electrical fires, for which the other 14 extinguishers of the pro-

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TABLE 1. *Extinguishers used in the fire tests*

Extinguisher	Agent	Type	Range	Approximate discharge duration
	Vaporizing liquid:		*ft*	*sec*
1	1 qt of CCl_4	Hand pump	20	50 to 60
2	do	do	20	50 to 60
3	do	Stored pressure	20 to 25	22
4	1 qt of chlorobromomethane	do	20 to 25	22
5	1½ qt of CCl_4	Hand pump	20	50
6	do	do	20	90
7	do	Stored pressure	20 to 25	22
8	2 qt of CCl_4	do	20 to 25	36
	Carbon dioxide:			
9	2½ lb	Quick-opening valve	4	16
10	5 lb	do	6	25
11	10 lb	do	8	43
	Dry chemical:			
12	4 lb	Cartridge-type	5 to 15	11
13	4 lb	Stored pressure	5 to 15	13
14	5 lb	do	2 to 10	17
	Foam:			
15	1¼ gal	Used with commercial packaged charge	30 to 35	40

gram were acceptable. The discharge, once initiated, could not be terminated before total exhaustion. Commercial foam materials, which had been previously found to give consistently good performance, were used for the charge.

Manufacturers' charging instructions were followed closely. In most cases charges were established on a weight basis, with a tolerance of ±0.05 lb. However, to provide a space of constant volume for the gas in stored pressure vaporizing liquid and dry chemical extinguishers, the charge weight in these devices was regulated to 0.01 lb. In order to minimize the intake of moisture into stored pressure extinguishers, which might adversely affect the charge in dry chemical devices or cause deterioration of the working parts of vaporizing liquid models, oil-pumped nitrogen was used as the expelling gas.

Discharge rate curves, determined empirically for extinguishers at approximately 70°F, are shown in figure 1. Rates for hand-pump carbon tetrachloride extinguishers were based on average performance, using a pumping rate of approximately one full cycle per second.

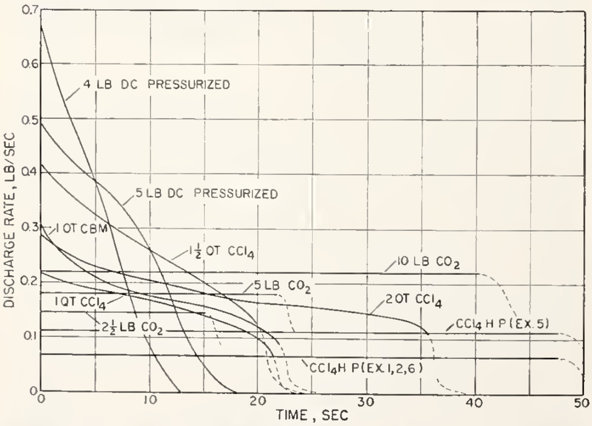

FIGURE 1. *Approximate discharge rates of test extinguishers.*

3. Description of Test Methods

The three types of fires that have served as standard tests of small extinguishers for flammable liquids are the 4-ft-square spill area, a cotton-waste fire, and a nominal 2-ft-diameter tub. Four types were representative of fires in partially enclosed spaces, with or without an obstacle to free dispersal of the extinguishing agent. The enclosed space was simulated by a metal compartment in which changes in the opening could be effected by removal in whole or part of the end plates and top. The design of three of these types of fires was such that the fuel consumption rates were maintained at approximately the same level. The components of the compartment, as well as the pan used both alone and as the fuel container in the enclosed space, are shown in figure 2. The construction of the parts is shown in figure 3. In addition, three other types of possible hazard were simulated. These included an open, shallow pan, a leaking container, and a spill flowing over a wide vertical surface.

As the extinguishers were intended primarily for flammable-liquid fires, the structures used in the several fire configurations were of noncombustible materials, although in certain tests a measured amount of an ordinary combustible, wood,

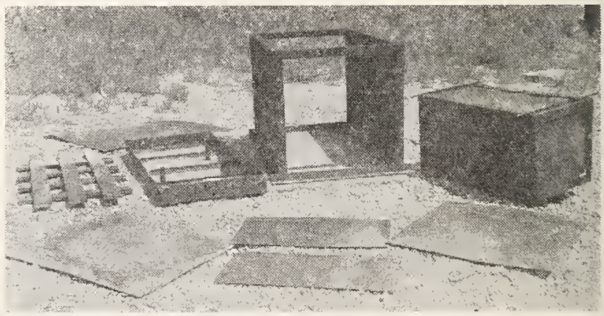

FIGURE 2. *Compartment components, pan, and wood grating.*

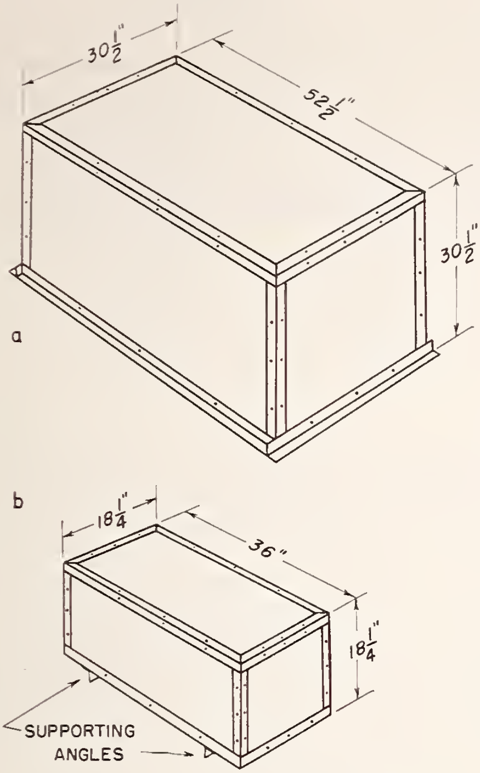

Figure 3. *Compartment and obstacle.*

Both units made from 2-in. by 2-in. by 1/8-in. angle and 14 gage steel plate fastened with 1/4-in. bolts.
a, Compartment made with bottom open, long sides covered, top and end plates removable ; b, obstacle covered on all sides.

was introduced as a means of determining the effectiveness of the extinguishers on mixed fires. The fuel used in all but one of the tests was a commercial mixture of heptanes having a narrow distillation range at approximately 200° F. This fuel, rather than gasoline, was used in order to create reproducible conditions of fuel consumption throughout the program, as well as to provide fair burning equilibrium during the course of a single trial. The distillation curves for the test fuel and the average of a number of gasolines are shown in figure 4.[1] The properties of gasoline are known to fluctuate seasonally, and vary with the producer and point of origin. Gasoline, also, because of its wide volatile range, exhibits marked differences in characteristics during the burning of a specimen, with rapid consumption of the more volatile portion and ending in progressively slower consumption of heavy fractions. Radiant-energy measurements for several gasolines and the heptane mixture were approxi-

[1] O. C. Blade, Bureau of Mines, Dept. Interior, National Motor Gasoline Survey of Summer 1954, Report of Investigation 5111 (January 1955).

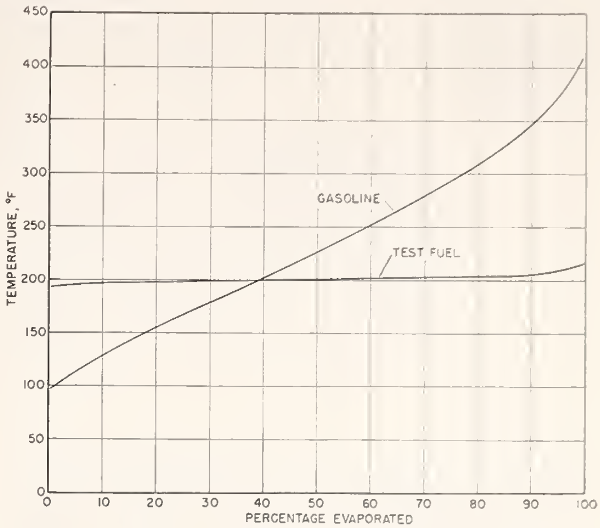

Figure 4. *Distillation curves of gasolines and test fuel.*

Gasoline curve represents average of 350 regulars tested mid-Atlantic States, summer, 1954.

mately the same. In duplicate tests, made with the two fuel types, no appreciable differences were noted in extinguisher performance that could be attributed to the type of fuel used. To introduce the effect of another type of fuel, an exception was made in the case of the vertically flowing spill fire, in which alcohol was used.

Fuel-consumption rates were determined from time to time during the program to check the consistency of the tests. However, it was noted that changes in ambient conditions, which ranged from calm to moderately high wind and from 32° to 85° F, had little significant effect on the fuel consumption.

Each of the test fires is described, with pertinent data, in table 2. The pan used in fires VI through X had dimensions of 4 by 24 by 48 in. The fuel in the pan, as well as in the 2-ft tub, was poured over approximately 1 in. of water. The four types of wood gratings used on the pan to control the burning rate, as well as to add a fuel complication, are shown in figure 5. The arrangement of openings in the compartment for fire types VII to X are shown in figure 6.

In the program, a test of each of the 15 extinguishers on the 10 types of fires, defined here as a series, was repeated 5 times to provide sufficient data for a significant statistical analysis of the results. The experiment was programed so that the intercomparison among extinguishers would not be affected by differences in weather conditions or other factors changing with time. Generally, it was possible to conduct tests of all 15 extinguishers on a single type of fire in a day. The schedule was so arranged that each day's oper-

TABLE 2. *The 10 test fires*

Fire model number	Description	Fuel	Preburn time	Fuel-consumption rate
		gal	*sec*	[a]*ml/sec*
I	4- by 4-ft fuel spill on concrete	⅝ heptane	5	Approx. 40.
II	8 lb of cotton waste, fuel saturated, 2 by 4 ft	½ heptane	10	
III	2-ft-diam tub, 12 in. high	do	20	Approx. 10.5.
IV	1-gal bucket, 0.161-in. hole 1 in. above bottom	¾ heptane	20 (after 10-sec flow)	14 to 10 (0 to 60 sec).
V	Flow down vertical surface, 34 in. wide; 36 in. high	1 ethyl alcohol	30 (after 10-sec flow)	11.5.
VI	Shallow pan, wood grating C on top	1 heptane	60	15±1.
VII	Compartment, top open; pan and wood grating A	do	60	12±1.
VIII	Compartment, top and 2 lower ends open; pan and wood grating B.	do	60	17.8±.7.
IX	Compartment, top and 1 end open; pan and wood grating C.	do	60	19.2±.7.
X	Compartment, 1 end and adjacent 4 in. at top open; pan and wood grating D.	do	60	18±1.2.

[a] 1 ml=0.000264 gal.

ation was divided into 5 time periods of 3 extinguishers each. In the course of the program, all 15 extinguishers were used in each of the time periods on each fire.

While comparatively experienced operators were used, the results were nevertheless influenced by the operators' techniques and to some extent by experience acquired in the tests. In an effort to simulate actual conditions as nearly as possible, no special protective equipment was provided the operators. In attacking fires, the approach was as close as that allowed by the intensity of the radiant heat, or as near as that required for the apparent optimum use of the extinguishers.

The data taken during each test included various observations of weather conditions, such as temperature, wind velocity and direction, barometric pressure, and humidity. Temperatures of the fuel and the extinguishers, the latter maintained at approximately 70° F, were noted. The method of attack and the amount of extinguishing agent expended were also recorded.

An attempt was made to take into consideration essential information that would be lost if rating were simply on the basis of percentage of success or failure. This was done by assigning a score to each trial. An arbitrary rating system was established, based on six levels of success, ranging from +3 to −3, with the plus scores assigned to cases in which the fire was extinguished, highest number for easiest accomplishment, and minus numbers for failures, −3 representing the case of least effectiveness. Generally, the plus ratings were based on the unexpended amount of extinguishing agent. Because in cases of failure the charge was completely spent, minus ratings ranging from −1, almost extinguished, to −3, no apparent attenuation, were assigned on the basis of the operators' judgment.

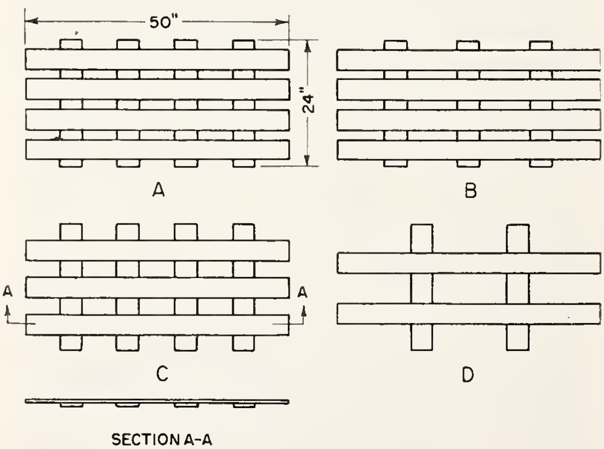

FIGURE 5. *Wood gratings.*

Gratings are constructed of Ponderosa pine, No. 2 common, nominal 1-in. by 4-in. mill lumber (dressed dimensions 25/32 in. by 3⅝ in.).

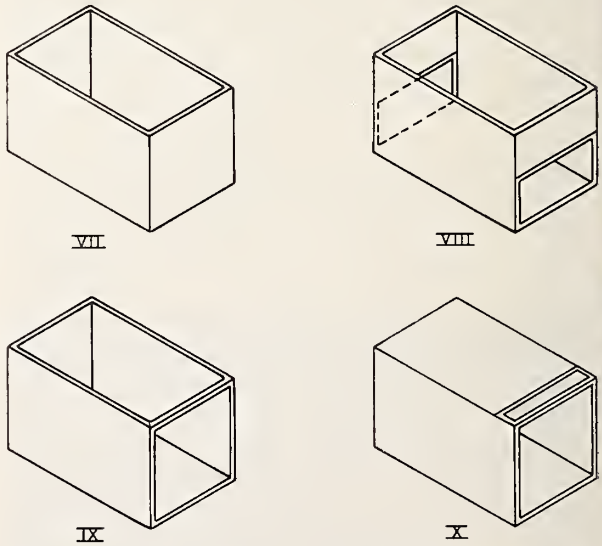

FIGURE 6. *Arrangement of compartment openings for extinguisher tests.*

Fuel pan, wood grating, and obstacle not shown.

4. Results

The performance ratings of the 5 trials of each of the 15 extinguishers on the 10 types of fires, 750 tests in all, are shown graphically in figure 7. Considering the 150 group results solely on the basis of success or failure in extinguishment, 94 showed complete agreement in the 5 runs, 30 had 1 disagreement, with the remaining 26 marked by a 3-and-2 split.

In the data for the 4- by 4-ft. spill fire (No. I), a dotted-circle designation indicates those cases in which extinguishment was accomplished after the fire area was considerably reduced from its original size. It was observed that this occurred in about 30 sec. Thus devices requiring more than this time to effect extinguishment are not comparable to those actually successful against the full-sized fire. For statistical purposes in ranking extinguishers, the dotted-circle designation was assigned a rating of +1.

The saturated cotton-waste fire (No. II) was characterized by nonuniformity of fire source during the extinguishment period as all or most of the liquid fuel was exhausted after about 60 sec of burning. This left a slow-burning-cotton fire not representative of a flammable-liquid hazard. Although in many cases there was momentary extinction of the flames by the time the extinguisher charge was exhausted, reignition usually occurred in the large body of glowing and smoldering material. In assigning performance ratings on this fire, results were considered successful if reignition did not occur within 5 min.

Table 3 gives the sums of the scores obtained on each of the 5 separate trials on the different test fires. A tabulation of the number of times each extinguisher succeeded in putting out the 10 fires is given in table 4. In table 5 the data show the differences between series. Each entry represents the number of successes of a given extinguisher summed over all fires in a series. A significant effect here is the fact that series 1 shows fewer successes than the remaining 4 series. The order of listing in tables 4 and 5 is roughly that of relative effectiveness achieved with the devices, but is also determined by grouping according to extinguisher type. Using the same arrangement, the relative rankings of the performance of the 15 devices, based on several methods of comparison, are presented in table 6. All methods of performance measurement give essentially the same rankings. Reasons for the omission of fire No. II in tables 4 and 6 are given in the following discussion.

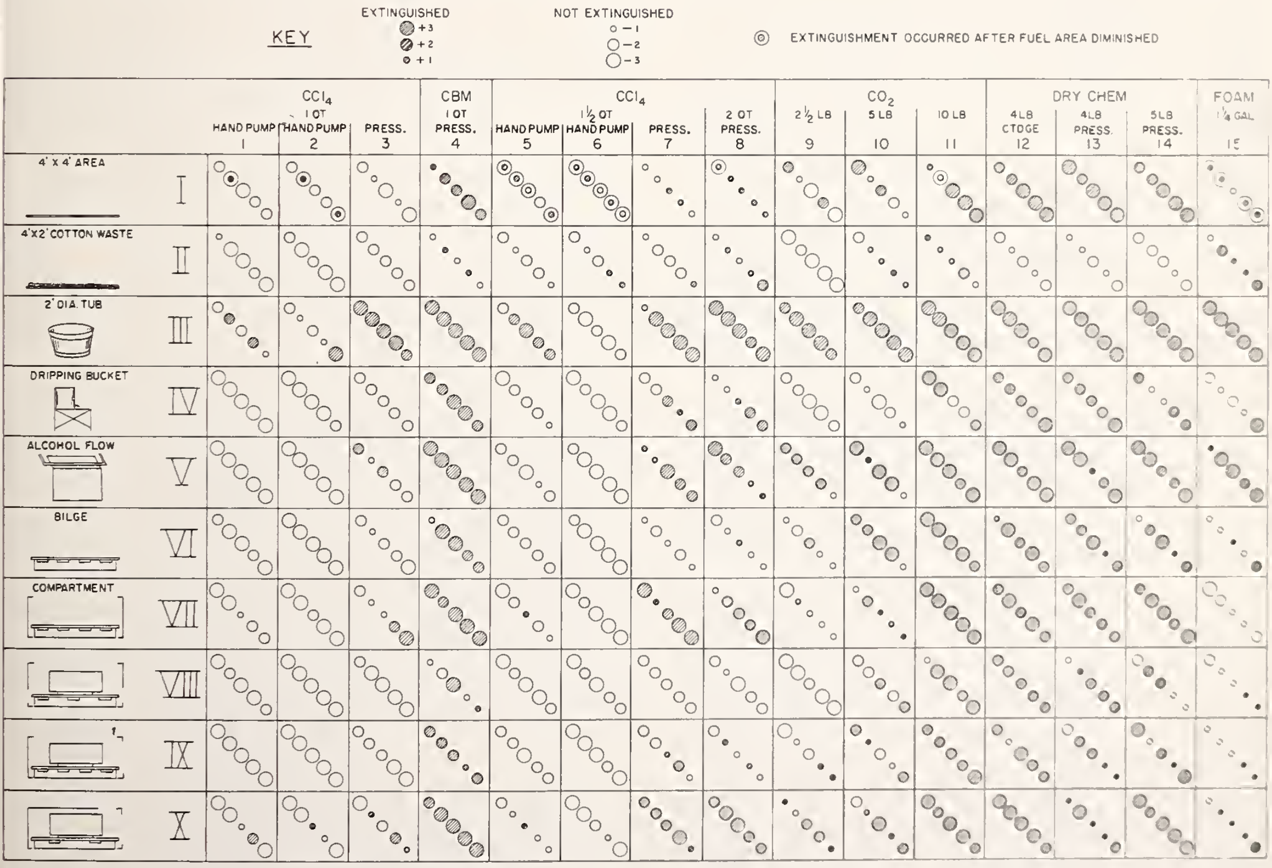

FIGURE 7. *Performance obtained with extinguishers on test fires.*

Table 3. *Sum of scores obtained with the 15 extinguishers on each of the 10 fire types (sum of 5 runs)*

Extinguisher	FIRE MODEL NUMBER									
	I	II	III	IV	V	VI	VII	VIII	IX	X
1	−8	−12	−1	−15	−15	−13	−11	−13	−15	−8
2	−4	−13	−3	−14	−15	−15	−14	−15	−15	−9
3	−10	−10	14	−10	−1	−10	1	−14	−12	−1
4	10	−1	15	12	15	11	14	0	9	14
5	2	−8	7	−10	−10	−10	−7	−13	−11	−4
6	5	−3	−12	−13	−14	−14	−14	−12	−14	−12
7	−1	−6	13	1	9	−7	12	−10	−2	10
8	5	2	14	3	9	−4	8	−10	−2	12
9	−3	−14	13	−12	7	−3	−3	−14	−4	5
10	1	2	14	−9	9	9	4	2	2	5
11	11	4	15	4	14	14	15	10	11	13
12	13	−8	14	11	14	11	12	10	8	14
13	14	−7	15	11	12	10	11	6	4	8
14	13	−9	15	4	13	7	13	0	8	14
15	3	5	15	−3	12	0	−9	−2	−1	4
Totals	+51	−78	+148	−40	+59	−14	+32	−79	−34	+65

Table 4. *Number of successes with each extinguisher in five trials on each fire type*

Extinguisher		FIRE MODEL NUMBER										Total number in 50 trials	Total number in 45 trials [a]
No.	Agent	I	II	III	IV	V	VI	VII	VIII	IX	X		
2	CCl_4	2	0	1	0	0	0	0	0	0	1	4	4
1	CCl_4	1	0	2	0	0	0	0	0	0	1	4	4
6	CCl_4	5	2	0	0	0	0	0	0	0	0	7	5
5	CCl_4	4	0	4	0	0	0	1	0	0	1	10	10
3	CCl_4	0	0	5	0	2	0	2	0	0	3	12	12
7	CCl_4	2	1	5	3	5	0	5	0	2	5	28	27
8	CCl_4	5	3	5	3	5	1	4	0	3	4	33	30
15	Foam	4	4	5	1	5	2	0	2	2	4	29	25
9	CO_2	2	0	5	0	4	1	2	0	2	4	20	20
10	CO_2	2	4	5	0	4	4	4	2	2	5	32	28
11	CO_2	5	4	5	3	5	5	5	4	5	5	46	42
14	Dry chemical	5	0	5	3	5	4	5	2	4	5	38	38
13	do	5	0	5	5	5	5	5	4	4	5	43	43
12	do	5	0	5	5	5	5	5	5	4	5	44	44
4	Chlorobromomethane	5	2	5	5	5	5	5	2	5	5	44	42
	Totals	52	20	62	28	50	32	43	21	33	53	394	374

[a] Omitting fire No. II.

Table 5. *Total number of successes with each extinguisher on all 10 fire types in each of the 5 series*

Extinguisher	Series					Total for 5 Series
	1	2	3	4	5	
2	0	1	1	0	2	4
1	0	2	0	2	0	4
6	1	1	1	2	2	7
5	1	2	4	1	2	10
3	2	2	2	3	3	12
7	4	4	7	7	6	28
8	4	7	7	8	7	33
15	3	5	5	7	9	29
9	4	3	5	5	3	20
10	5	7	8	6	6	32
11	9	10	9	9	9	46
14	7	7	8	8	8	38
13	7	9	9	9	9	43
12	9	8	9	9	9	44
4	8	9	9	9	9	44
Totals	64	77	84	85	84	394

Table 6. *Performance obtained with test extinguishers*

Extinguisher	Agent and amount	Type	A Percentage of success	B Percentage of success, omitting fire 11	C Average scores	D Average scores, omitting fire 11	Ranking according to— A	B	C	D
2	CCl_4, 1 qt	Hand pump	8	9	−2.3	−2.3	1.5	1.5	1	1
1	CCl_4, 1 qt	do	8	9	−2.2	−2.2	1.5	1.5	2	3
6	CCl_4, 1½ qt	do	14	11	−2.1	−2.2	3	3	3	2
5	CCl_4, 1½ qt	do	20	22	−1.3	−1.2	4	4	4	4
3	CCl_4, 1 qt	Pressurized	24	27	−1.1	−1.0	5	5	5	5
7	CCl_4, 1½ qt	do	56	60	0.4	0.6	7	8	7	8
8	CCl_4, 2 qt	do	66	67	.7	.8	10	10	10	10
15	Foam, 1¼ gal		58	56	.5	.4	8	7	8	7
9	CO_2, 2½ lb		40	44	−.6	−.3	6	6	6	6
10	CO_2, 5 lb		64	62	.7	.7	9	9	9	9
11	CO_2, 10 lb		92	93	2.2	2.5	15	12.5	15	15
14	Dry chem., 5 lb	Stored pressure	76	84	1.6	2.0	11	11	11	11.5
13	Dry chem., 4 lb	do	86	96	1.7	2.0	12	14	12	11.5
12	Dry chem., 4 lb	Cartridge	88	98	2.0	2.4	13.5	15	13.5	14
4	Chlorobromomethane, 1 qt	Stored pressure	88	93	2.0	2.2	13.5	12.5	13.5	13

5. Discussion of Results

In considering the 94 groups of consistent results where either extinguishment or failure occurred in all five trials of a device on a particular fire, it may be assumed that the performance effectiveness of these extinguishers was such that variations in weather conditions and operator skill during any of the five runs was not sufficiently great as to change the outcome. The relative success or failure scorings within a group, however, were affected by these variables.

Almost uniform success was possible in fighting fires with some extinguishers, whereas with some others there was equally consistent noneffectiveness. Also, the application of a certain extinguisher may have been a success against a minor fire on every trial, yet may have resulted in complete failure on a more severe type of hazard. The performance obtained with such a device on a fire of intermediate severity frequently resulted in neither all success nor all failure; success could depend on the right combination of environmental conditions and operator technique. If trials of an extinguisher showed a low percentage of success against a particular fire, these successes must have been achieved under a very restrictive set of conditions. On the other hand, a device with which a high percentage of success was achieved could be said to be less sensitive to minor deviations from optimum operating conditions. In these tests, extinguishers used in trials characterized by a large number of nonuniform group results appear to be high-sensitivity-type devices.

The fire configuration seems to be of considerable importance in the effectiveness of extinguishment. The poorer performance obtained with carbon tetrachloride type extinguishers on fire VI than on VII may be attributed to the lack of confining surfaces on the shallow-pan fire. This causes a reduction in the volume of decomposition products, which are best produced by vaporization against a hot surface. Also, there is no means of preventing the rapid dissipation of the volatile gases that are formed. A specialized method of attack with carbon tetrachloride is illustrated by fire IV, in which fuel is fed through a small opening. By directing the stream of vaporizing liquid directly at the source, the fuel could sometimes be diluted to a point at which it no longer sustained combustion.

In fire models VIII, IX and X, where the fuel consumption rates throughout the program were approximately equal (18.5 ± 1.4 ml/sec), confinement was apparently the primary factor affecting extinguisher performance. The test devices showed significantly greater effectiveness on a fire model such as No. X, in which the highly confined configuration tended to accumulate the agent to a concentration level necessary for extinguishment.

Accumulation of vaporizing agent, however, may not be the only explanation for this apparent correlation between degree of confinement of fire models and effectiveness of extinguishment. The relation of the agent to the flammable limits of the fuel, which for heptane range from 0.8 to 7 percent, may well be another factor. Even with approximately equal fuel-consumption rates, the three fires, VIII, IX and X, were not necessarily burning at the same fuel/oxygen ratio. It is possible that in fire X the configuration is such that air diffusion is restricted, especially as compared with No. VIII, with the apparent result that the fuel mixture was considerably richer than in other fires. On the basis of flammability limit tests, it has been suggested that the volume of vaporizing liquids (and perhaps other agents) required for such a fire is much less than that for fires having a lean mixture caused by an excess of available air.[2]

In conducting the tests, it was found that optimum methods of attack varied with the fire model and particularly with the extinguishers. Generally, carbon tetrachloride was best employed by spraying on a hot surface to secure maximum vaporization, and in such manner as to cover the area with the decomposition products. Dry chemical extinguishers were most effective when operated to cover the whole flaming area at once. Carbon dioxide types seemed to work best when the agent was discharged in a sweeping motion near the fuel surface. Foam was effective only if it could be flowed onto the burning-liquid surface; its use was difficult in the presence of obstructions. To secure results that would be impartial and unprejudiced, the operators in every case endeavored to use an extinguisher to its maximum effectiveness. That this generally occurred is borne out by the fact that after increases from the first to third series, attributable to a learning effect, the number of successes in the last three series of tests remained approximately constant.

An inspection of the data of table 4 suggests that fire II is not representative of the same class of hazard as the other nine fires. It will be noted that fire VIII has about the same low number of successes, but it nevertheless ranks the extinguishers in essentially the same order as the remaining fires. A discordant ranking is given by fire II, and for this reason further analysis has been carried out omitting this fire. This anomalous behavior is confirmed by a statistical analysis on the data of table 4.

Omitting fire II, the other nine fires can be ranked in order of severity (most difficult to extinguish has rank 1) as follows:

Fire	Percentage of times fire put out in 75 attempts	Rank	Average scores from 75 attempts	Rank
VIII	26.7	1	−1.05	1
IV	37.3	2	−0.53	2
VI	42.7	3	−.19	4
IX	44.0	4	−.45	3
VII	57.3	5	.43	5
V	66.7	6	.79	7
I	69.3	7	.68	6
X	70.7	8	.86	8
III	82.6	9	1.97	9

While it would be convenient to have a measure on a continuous scale, such as the area of a given type fire that could be put out, it is considered that adequate screening of the effectiveness obtainable with the extinguishers can be achieved by use of several fires selected from those employed in this program. From the results, it can be seen that when fire III is not extinguished, the performance is certainly weak in relation to the over-all performance available with the extinguishers used in this test. If trials are successful on fire III, performance could be further tested on an intermediate fire, such as VII, and a difficult one, fire VIII.

For practical purposes, a standard of performance would have to be set. It is suggested that extinguishment could be defined, for example, as success in putting out a particular test fire 4 times in 5 trials, and further, to achieve an average score as described herein of approximately +1 or greater. It should be remembered, however, that even fire VIII, the most difficult test, does in no manner encompass the limit of possible hazards, but rather defines the limit of extinguishing capacity obtainable with devices of a size and type considered in this program.

Although the fire-test program was conducted outdoors under a wide variety of ambient conditions, the results based on scoring did not show an appreciable influence of any individual measured ambient factor, with the exception of wind speed. What appears to be a significant day-to-day variation for some fires is actually almost entirely due to the increase in scores from the first to the subsequent series.

Analysis of the data indicates that wind speed, as a single variable, showed some statistically significant effect on the scores of only a few types of fires. The degree of wind sensitivity depended more on fire type than on type of extinguisher. Scores obtained on fires II, IV, and VI were adversely affected by increase in wind velocity, whereas scores on fire VII seemed to be favorably influenced by this condition. The rest of the fire models showed no significant trend in the scoring. The great number of cases of scores remaining unchanged by the effects of ambient conditions is considered to indicate the relative reproducibility of the scoring system used.

As had been expected, a high rate of discharge in any particular type of extinguisher seemed to enhance the effectiveness of the performance. This is shown in an examination of the results of tests with hand-pump and stored-pressure-type carbon tetrachloride devices, and also the 5-lb dry chemical extinguisher as against the two 4-lb models.

Using the 15 extinguishers tested, trials with only three, the 10-lb carbon dioxide and the two 4-lb dry chemical devices, met the suggested requirements mentioned earlier for the most severe fire, No. VIII. Trials with the 1-qt chlorobromomethane extinguisher narrowly missed the suggested performance on this fire, but because of high effectiveness when used on the other fires, this device stands with the other three extinguishers in a group with which the highest percentage of success for the whole program was attained. The 5-lb dry chemical, 5-lb carbon dioxide, and 1½- and 2-qt stored-pressure carbon tetrachloride extinguishers gave suitable results when used on an intermediate fire such as No. VII. The suggested

[2] E. H. Coleman and G. W. Stark, A Comparison of the extinguishing efficiency of bromochloromethane and carbon tetrachloride, Chemistry & Industry, p. 563 (1955).

minimum requirements would be obtained on fire III with the 1¼-gal foam extinguisher, the 2½-lb carbon dioxide, the 1-qt stored-pressure carbon tetrachloride and one of the 1½-qt hand-pump carbon tetrachloride devices. The two 1-qt and the remaining 1½-qt vaporizing-liquid hand pumps were unsuited for use on even this minimum fire, although it has been long considered a standard test for evaluating small extinguishers of this type. The results with these last extinguishers have been corroborated by other investigators.[3]

In considering ease of handling of the several types with which the most successful operation was attained and the possibility of their successful use by a novice, it is necessary to remark that the 10-lb carbon dioxide extinguisher, while effective, has a charge weight 2½ times that of other devices in its effectiveness group, and a total weight in excess of 3 times that of the next heaviest. This extinguisher also has a relatively short discharge range, forcing a close approach to the fire for effective use. The stored-pressure chlorobromomethane device may be operated at a considerable distance (up to 20 ft) from a fire. The dry chemical extinguishers are, however, the type most likely to lend themselves to effective use as their moderate-to-good range and high accomplishment for their size are further augmented by the shielding effect that the powder affords against radiant heat.

[3] T. B. Edwards, Army Fire Extinguishment Research Program for Field Operation, Proc. Symposium on Fire Extinguishment Research and Engineering (U. S. Naval Civil Engineering Research and Evaluation Laboratory, Port Hueneme, Calif., November 1954).

Washington, November 16, 1956.

6. Conclusions

The following conclusions seem justified on the basis of the results of the test and the observations made thereon:

The test fires used for the study presented a useful scale for evaluation of extinguishing performance. From these, a group of three fires can be selected to provide a qualitative means for measuring the performance obtainable with other devices intended for use on flammable-liquid fires, especially those in hydrocarbon fuels.

The rather large variations in ambient conditions observed during the test did not affect extinguishing performance enough to cause statistically significant differences to appear in the results for most fire types.

Erratic results obtained with some of the extinguishers on certain fires could be ascribed to particular sensitivity of the extinguisher, perhaps related to an unmeasured variable, to the conditions of the fire test, and to the technique of the operator.

The apparent differences previously noted in the effectiveness obtainable with various types and sizes of extinguishers, all of which have sometimes been equally rated for use on small flammable-liquid fires, have been generally substantiated by the results of the tests conducted in this program.

Extinguishers of the type of the 1-qt chlorobromomethane, 10-lb carbon dioxide, and 4-lb dry chemical devices described herein ranked very closely with each other as useful devices for attack on the test fires, and were superior to the other types of extinguishers used in this program on flammable-liquid fires of limited extent.

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