HALON ALTERNATIVES EXTINGUISHMENT TESTING

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INTRODUCTION

Halon firefighting agents, like chlorofluorocarbons (CFCs), have the potential to deplete stratospheric ozone and accelerate global warming. The potential threat to the global environment has been considered so serious that, in 1987, the Montreal Protocol included production restrictions on halons as well as CFCs. Halons are clean, effective, and have low toxicities. They can be used around electronic equipment, aircraft engines, computer facilities, and museum exhibits without damage due to residue. Generally there are five requirements for halon alternatives: cleanliness, low ozone depletion potential (ODP), low global warming potential (GWP), low toxicity, and effectiveness. In anticipation of production decreases, halon alternatives development has been underway at the New Mexico Engineering Research Institute (NMERI) since 1986. This paper discusses the fire extinguishment effectiveness tests employed in the NMERI development program. Laboratory-scale discharge, modified cup-burner, and field-scale suppression test methodologies are discussed.

A program has been established to develop test methods for achieving the goal of finding halon replacements. These new test methods measure candidate effectiveness as both total-flood and streaming extinguishing agents. Currently, the laboratory cup-burner test is the standard method to determine the extinguishment concentration of an agent. At this time, there are no known standard laboratory-scale discharge tests to measure the effectiveness of an agent applied by streaming. A full-scale and two reduced-scale laboratory cup burners and several prototype laboratory-scale discharge apparatuses have been designed and built to measure total-flood and streaming extinguishment characteristics. Standardization tests have been performed on the cup burners using seven compounds that have a wide range of chemical and physical characteristics. Methods have been developed to analyze fluid-flow characteristics within the cup burners and are being developed for the laboratory-scale discharge apparatus. Standard small-, medium-, and large-scale field test methodologies are also being designed and evaluated to determine agent extinguishment characteristics. The laboratory tests are performed on a wide range of potential halon alternatives, while large-scale tests are used for those candidates that pass selected screening criteria. The overall effort described here is the development of standard laboratory and field-test protocols. This is done to ensure that test results can be compared accurately among research organizations as potential halon replacements are developed. It is beyond the scope of this paper to present all of the test data to date. We are also excluding medium- and large-scale test results and methodologies.

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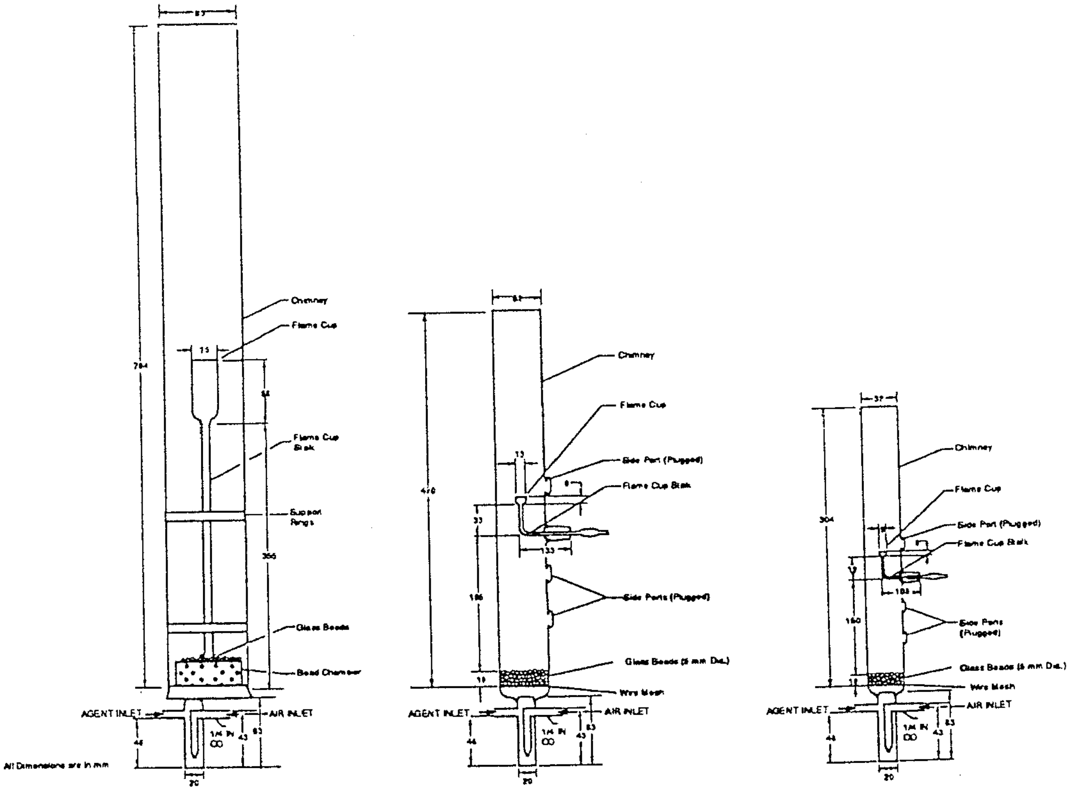

(a) Full-Scale (b) 5/8-Scale (c) 2/5-Scale

Figure 1. The NMERI Cup Burners.

CUP-BURNER APPARATUS

The cup-burner apparatus was developed to determine extinguishment concentrations required to extinguish a flame. The typical cup-burner apparatus is shown in Figure 1a (full-scale cup-burner). A small glass chamber for air/extinguishing agent mixing is connected to the bottom of the chimney. Gaseous agents are directed through a flow meter, and liquid agents are metered with a syringe pump. Different techniques and equipment are used for gaseous and liquid agents. Air/agent mixing and liquid vaporization occur in the mixing chamber. Mixing is completed as the agent/air mixture continues through glass beads at the bottom of the chimney. Once past the beads, the vaporized mixture continues upward through the chimney past the flame. Air and agent volumetric flow rates are used to calculate the volume percent concentration of agent required for flame extinguishment.

During the fall of 1988, it became apparent that the volume of an alternative agent required to obtain results from the standard (full-scale) cup burner was too great. The cost of candidates prepared at the laboratory-scale is often high and in many cases, only small volumes of agents are available. Therefore, two scaled-down versions of the full-scale cup burner have been designed and constructed. The first version is a 5/8-scale apparatus with inclusion of four side ports for thermocouple access and for ignition (Figure 1b). The second scaled-down cup burner is a 2/5-scale apparatus (Figure 1c). The scales give the size reduction in all linear dimensions.

CUP-BURNER STANDARDIZATION TESTING

Standardization testing has shown the validity of the 5/8-scale and 2/5-scale cup burners as compared with the full-scale cup-burner results. Standardization tests have been performed on all three cup burners using two liquids, Halon 2402 and HCFC-30, and five gases, CFC-12, Halon 1211, Halon 1301, nitrogen, and carbon dioxide (Table 1). Extinguishment concentrations have been obtained for all of the agents with all of the cup burners, and comparisons have been made with each agent for each apparatus. The halons, with known extinguishment capabilities are used as standards. HCFC-30 was chosen because it is a low boiling liquid and fairly easy to vaporize. CFC-12 gives a halocarbon with an intermediate extinguishment concentration. Nitrogen and carbon dioxide represent materials that effect flame extinguishment by physical means.

TABLE 1. CUP-BURNER STANDARDIZATION COMPOUNDS.[a]

Halocarbon number	Common name	Formula	Density (g/ml)	B.P. (°C)	M.W. (g/mol)	State
12	Freon® 12	CCl_2F_2	1.13	-29.79	120.91	Gas
12B1	Halon 1211	$CBrClF_2$	1.83	-3.33	165.36	Gas
13B1	Halon 1301	$CBrF_3$	1.54	-57.8	148.91	Gas
30	Dichloromethane	CH_2Cl_2	1.32	40.0	84.93	Liq.
114B2	Halon 2402	$C_2Br_2F_4$	2.16	47.3	259.8	Liq.
----	Nitrogen	N_2	0.96	-195.8	28.01	Gas
—	Carbon Dioxide	CO_2	1.50	-78.5	44.01	Gas

[a] *n*-Heptane is the standard fuel.

In order to achieve comparable test data, all three cup burners require similar fluid-flow characteristics throughout. A quick and easy procedure has been developed to perform the needed fluid-flow calculations and to compare the relevant flow parameters to find what alterations, if any, are needed in the testing procedure. This has been accomplished by creating a computer spreadsheet, which contains the dimensions of the cup burners, the physical characteristics of the tested agents, and the volumetric flow rates of air and agent through the apparatus. The spreadsheet physical property data to calculate velocities, Reynold's numbers, and pressure drops throughout the three cup burners. Table 2 compares some important characteristics of the cup burners. Figure 2 shows actual extinguishment concentration for Halon 1211 versus total air/agent flow rates. The standardization efforts have established the air/agent flow rate operating range for the cup burners.

TABLE 2. NMERI CUP-BURNER CHARACTERISTICS.

	Min. amt. of agent req.			Calculated values at the flame cup.[b]		
Cup-burner size	gas (g)	liq. (mL)	Outside dimensions[a]	Re number	Air/Agent velocity	Pressure Drop
full	1000	100	83 x 764	26,403	0.09 m/s	0.0020 pa
5/8	500	25	52 x 470	45,581	0.22 m/s	0.0010 pa
2/5	100	15	32 x 308	68,352	0.59 m/s	0.0053 pa

[a] Dimensions are in mm.

[b] Total flow rate of 13,300 mL/min.

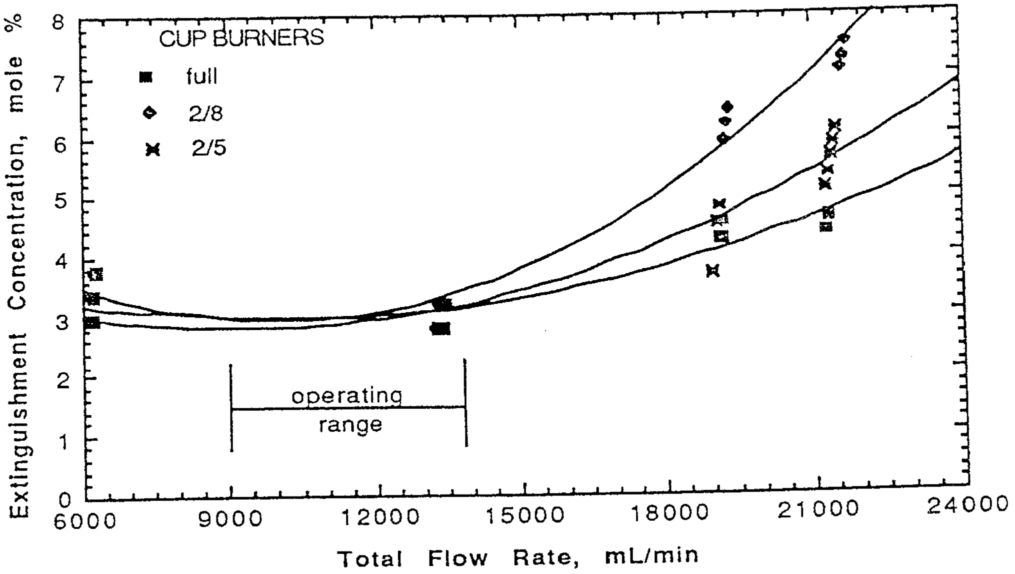

Figure 2. Halon 1211 extinguishment concentration versus total flow rate for the NMERI cup burners.

CUP-BURNER TESTS

Part of the initial cup-burner work evaluated synergism (the interaction of two chemicals such that a mixture gives better extinguishment than would be predicted from the properties of the components). Halon 1211 was combined with several halocarbons in the full-scale cup-burner apparatus, and the neat and combined individual extinguishment concentrations were compared. CFC-12, CFC-114, and HCFC-22 were used in these experiments. Halon 1211 showed synergistic effects in combination with all three chemicals. These test results show promise for blends of agents to improve extinguishment capability and to reduce toxicity, ODP, GWP, and other undesirable characteristics.

Cup-burner testing of halocarbons continues. This effort has been expedited by the construction of a database to aid in selecting and characterizing candidates. The database has been used to select approximately 90 compounds and these have been obtained for testing (Table 3); initial test results are available for 50 of these. Note that only a few of these are being considered as halon alternatives, a variety of compounds are being tested to refine the fire suppression test apparatuses and suppression prediction algorithms that have been developed.

TABLE 3. HALOCARBON TEST COMPOUNDS.

Halocarbon number	Common name	Formula	B.P., °C	M.W., g/mol	Est. ext. concentration[a]	Estimated toxicity
CHLOROCARBONS (CCs)						
10	Tetrachloromethane	CCl_4	76.7	153.82	4.87	High
110	Hexachloroethane	CCl_3CCl_3	247.0	285.2	3.5	High
HYDROCHLOROCARBONS (HCCs)						
30	Dichloromethane	CH_2Cl_2	40.0	84.93	8.56	Med.
40	Chloromethane	CH_3Cl	-24.2	50.49	15.00	High
120	Pentachloroethane	$CHCl_2CCl_3$	162.0	202.3	4.06	High
130	1,1,2,2-Tetrachloroethane	$CHCl_2CHCl_2$	146.2	167.8	4.87	High
130a	1,1,1,2-Tetrachloroethane	CCl_3CH_2Cl	130.5	167.8	4.87	High
140	1,1,2-Trichloroethane	$CHCl_2CH_2Cl$	113.8	133.4	6.15	High
140a	1,1,1-Trichloroethane	CCl_3CH_3	74.1	133.4	6.15	High
150	1,2-Dichloroethane	CH_2ClCH_2Cl	83.5	98.96	8.55	High
150a	1,1-Dichloroethane	$CHCl_2CH_3$	57.3	98.96	8.55	High
160	Chloroethane	CH_3CH_2Cl	12.3	64.51	15.00	?
220	Heptachloropropane	$CCl_3CCl_2CHCl_2$	247.0	285.21	3.09	?
240	1,1,2,3,3-Pentachloropropane	$CHCl_2CHClCHCl_2$	198.0	216.32	4.06	?
250	1,1,1,3-Tetrachloropropane	$CH_2ClCH_2CCl_3$	159.0	181.9	4.87	High
250	1,2,2,3-Tetrachloropropane	$CH_2ClCCl_2CH_2Cl$	179.0	181.9	4.87	Med.
250	1,1,2,3-Tetrachloropropane	$CH_2ClCHClCHCl_2$	179.0	181.9	4.87	?
250	1,1,1,2-Tetrachloropropane	$CCl_3CHClCH_3$	150.0	181.9	4.87	?
260	1,2,3-Trichloropropane	$CH_2ClCHClCH_2Cl$	156.8	147.4	6.15	High
260	1,1,2-Trichloropropane	$CHCl_2CHClCH_3$	140.0	147.4	6.15	?
270	2,2-Dichloropropane	$CH_3CCl_2CH_3$	69.3	113.0	8.55	Med.
270	1,3-Dichloropropane	$CH_2ClCH_2CH_2Cl$	120.4	113.0	8.55	?
270	1,2-Dichloropropane	$CH_2ClCHClCH_3$	88.1	113.0	8.55	Med.
280	2-Chloropropane	$CH_3CHClCH_3$	35.7	78.5	15.00	?
280	1-Chloropropane	$CH_2ClCH_2CH_3$	46.6	78.5	15.00	High
FLUOROCARBONS (FCs)						
14	Perfluoromethane	CF_4	-128.0	88.0	15.94	Low
116	Perfluoroethane	CF_3CF_3	-78.2	138.0	11.47	Low
218	Perfluoropropane	$CF_3CF_2CF_3$	-36.0	188.0	9.08	Low
[b]C318	Perfluorocyclobutane	C_4F_8	-4.00	200.0	9.1	Low
n/a	Perfluoro-1,3-dimethylcyclohexane	C_8F_{16}	101.0	400.1	5.18	Med.
n/a	Perfluoromethylcyclohexane	C_7F_{14}	75.0	350.0	5.78	?
n/a	*n*-Perfluorohexane	C_6F_{14}	57.11	338.0	5.78	?
n/a	*n*-Perfluoroheptane	C_7F_{16}	99.0	388.0	5.18	Med.
HYDROFLUOROCARBONS (HFCs)						
23	Trifluoromethane	CHF_3	-82.0	70.01	20.14	Low
32	Difluoromethane	CH_2F_2	-51.6	52.02	27.99	Low
41	Fluoromethane	CH_3F	-78.4	34.03	49.14	Med.
125	Pentafluoroethane	CHF_2CF_3	-48.5	120.02	13.30	?
134	1,1,2,2-Tetrafluoroethane	CHF_2CHF_2	-23.0	102.3	15.94	?

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[a] Estimated extinguishment concentration (in mole %) for cup-burner test, calculated using a predictive algorithm.

[b] Under small-scale evaluation.

TABLE 3. HALOCARBON TEST COMPOUNDS (CONTINUED).

Halocarbon number	Common name	Formula	B.P., °C	M.W., g/mol	Est. ext. concentration[a]	Estimated toxicity
HYDROFLUOROCARBONS (HFCs) (continued)						
143	1,1,2-Trifluoroethane	CHF_2CH_2F	5.00	84.0	20.14	Med.
[b]143a	1,1,1-Trifluoroethane	CH_3CF_3	-47.6	84.0	20.14	Med.
[b]152a	1,1-Difluoroethane	CHF_2CH_3	-24.7	66.0	27.99	Low
161	Fluoroethane	CH_3CH_2F	-37.7	48.1	49.14	?
221	2-Fluoropropane	CH_3CHFCH_3	n/a	62.1	49.14	?
236	1,1,1,2,3,3-Hexafluoropropane	$CF_3CHFCHF_2$	6.00	152.0	11.47	?
272	2,2-Difluoropropane	$CH_3CF_2CH_3$	-1.00	80.1	27.99	?
272	1,2-Difluoropropane	$CH_2FCHFCH_3$	n/a	80.1	27.99	?
CHLOROFLUOROCARBONS (CFCs)						
12	Dichlorodifluoromethane	CCl_2F_2	-29.79	120.91	7.21	Low
13	Chlorotrifluoromethane	$CClF_3$	-81.4	104.46	9.77	Low
112	1,2-Difluoro-1,1,2,2-tetrachloroethane	CCl_2FCCl_2F	92.8	203.8	4.45	Med.
112a	2,2-Difluoro-1,1,1,2-tetrachloroethane	$CClF_2CCl_3$	91.5	203.8	4.45	Med.
113	1,2,2-Trichloro-1,1,2-trifluoroethane	$CClF_2CCl_2F$	47.6	187.4	5.19	Med.
113a	2,2,2-Trichloro-1,1,1-trifluoroethane	CCl_3CF_3	46.0	187.4	5.19	Med.
114	1,2-Dichloro-1,1,2,2-tetrafluoroethane	$CClF_2CClF_2$	3.77	170.9	6.27	Low
115	2-Chloro-1,1,1,2,2-pentafluoroethane	$CClF_2CF_3$	-39.1	154.5	8.03	L/Med.
214	1,1,1,3-Tetrachloro-2,2,3,3-tetrafluoropropane	$CClF_2CF_2CCl_3$	n/a	253.8	4.12	?
216ab	1,2-Dichloro-1,1,2,3,3,3-hexafluoropropane	$CF_3CClFCClF_2$	34.5	220.9	5.57	High
217	2-Chloro-1,1,1,2,3,3-heptafluoropropane	$CF_3CClFCF_3$	n/a	204.5	6.86	Med.
n/a	1,3-Dichlorotetrafluorobenzene	$C_6Cl_2F_4$	165.0	219.0	6.28	Low
n/a	Chloropentafluorobenzene	C_6ClF_5	117.0	202.5	8.04	Low
HYDROCHLOROFLUOROCARBONS (HCFCs)						
20	Trichloromethane	$CHCl_3$	61.2	119.4	6.15	High
21	Dichlorofluoromethane	$CHCl_2F$	8.90	102.9	7.82	Med.
[b]22	Chlorodifluoromethane	$CHClF_2$	-40.0	86.47	11.01	Low
31	Chlorofluoromethane	CH_2ClF	-9.10	68.58	12.67	High
121	1-Fluoro-1,1,2,2-tetrachloroethane	CCl_2FCHCl_2	117.0	185.8	4.65	?
122a	1,1-Difluoro-1,2,2-trichloroethane	$CHCl_2CClF_2$	72.0	169.4	5.47	?
122b	1,2-Difluoro-1,2,2-trichloroethane	$CHClFCCl_2F$	73.0	169.4	5.47	?

[a] Estimated extinguishment concentration (in mole %) for cup-burner test, calculated using a predictive algorithm.

[b] Under small-scale evaluation.

TABLE 3. HALOCARBON TEST COMPOUNDS (CONCLUDED).

Halocarbon number	Common name	Formula	B.P., °C	M.W., g/mol	Est. ext. concentration[a]	Estimated toxicity
HYDROCHLOROFLUOROCARBONS (HCFCs) (continued)						
[b]123	2,2-Dichloro-1,1,1-trifluoroethane	CF_3CHCl_2	48.0	152.9	6.71	Med.
123a	1,2-Dichloro-1,1,2-trifluoroethane	$CClF_2CHClF$	30.0	152.9	6.71	Med.
124	2-Chloro-1,1,1,2-tetrafluoroethane	CF_3CHClF	-12.0	136.5	8.81	Med.
124a	1-Chloro-1,1,2,2-tetrafluoroethane	CHF_2CClF_2	10.2	136.5	8.81	Med.
[b]132b	1,2-Dichloro-1,1-difluoroethane	$CH_2ClCClF_2$	46.8	134.9	7.71	High
133a	2-Chloro-1,1,1-trifluoroethane	CF_3CH_2Cl	6.67	118.5	9.77	High
141a	1,2-Dichloro-1-fluoroethane	$CHClFCH_2Cl$	73.7	117.0	7.82	?
[b]141b	1,1-Dichloro-1-fluoroethane	CCl_2FCH_3	32.0	117.0	7.82	Med.
222	1,1-Difluoro-1,2,2,3,3-pentachloropropane	$CClF_2CCl_2CHCl_2$	168.4	252.3	3.78	Low
253	2-Chloro-1,1,1-trifluoropropane	$CF_3CHClCH_3$	30.0	132.5	9.77	?
BROMOFLUOROCARBONS (BFCs)						
12B2	Dibromodifluoromethane	CBr_2F_2	24.0	209.82	2.96	Low
13B1	Bromotrifluoromethane	$CBrF_3$	-57.8	148.91	4.41	Low
114B2	1,2-Dibromo-1,1,2,2-tetrafluoroethane	$CBrF_2CBrF_2$	47.3	259.8	2.46	High
HYDROBROMOFLUOROCARBONS (HBFCs)						
22B1	Bromodifluoromethane	$CHBrF_2$	-15.0	130.92	4.31	Low
123B2	1,2-Dibromo-1,1,2-trifluoroethane	$CBrF_2CHBrF$	76.0	241.8	2.51	Med.
123B2	2,2-Dibromo-1,1,1-trifluoroethane	CF_3CHBr_2	73.0	241.8	2.51	Med.
124B1	2-Bromo-1,1,1,2-tetrafluoroethane	CF_3CHFBr	n/a	180.9	3.99	?
142B1	2-Bromo-1,1-difluoroethane	CHF_2CH_2Br	57.0	145.0	4.31	High
BROMOCHLOROFLUOROCARBONS (BCFCs)						
12B1	Bromochlorodifluoromethane	$CBrClF_2$	-3.33	165.36	3.68	L/Med.
123aB1	1-Bromo-2-chloro-1,1,2-trifluoroethane	$CBrF_2CHClF$	50.0	197.4	3.56	Med.
HYDROBROMOCHLOROFLUOROCARBONS (HBCFCs)						
123B1	2-Bromo-2-chloro-1,1,1-trifluoroethane	$CHBrClCF_3$	52.0	197.4	3.56	Med.
OTHER						
n/a	Nitrogen	N_2	-195.8	28.01	39 (measured)	Med.
n/a	Carbon Dioxide	CO_2	-78.5	44.01	24 (measured)	Med.

[a] Estimated extinguishment concentration (in mole %) for cup-burner test, calculated using a predictive algorithm .

[b] Under small-scale evaluation.

DISCHARGE TESTING

Prototype laboratory-scale discharge extinguishment test apparatuses have been developed, constructed, and are now being evaluated. Halon 1211 is used as a low vapor pressure standard due to its known fire-extinguishing capability, while HCFC-22 is used as a gaseous standard. Preliminary work has been performed to compare the apparatuses, techniques, and extinguishment flow rates. Several apparatus configurations have been tested to develop a final prototype. This experiment shows the streaming extinguishment capabilities of potential halon replacements, as opposed to the total-flood extinguishment capabilities. Streaming extinguishment is important for portable fire extinguisher applications. Since performance of a streaming agent is highly dependent on throw characteristics, discharge testing provides important and useful parameters when developing new halon alternatives.

After laboratory testing, small-scale discharge testing is performed. The small-scale test uses a 6-in deep, 1-ft^2 square fire pan and *n*-heptane fuel (100 mL) floating on water. The agent is delivered from stainless steel cylinders, the weights of which are monitored to determine agent flow rates fire extinguishment. Both indoor and outdoor tests have been conducted. Seven compounds and their blends are currently in the small-scale testing stage. Medium- (4 to 28 ft^2) and large-scale (>150-ft^2) tests are conducted following smalle-scale testing.

SUMMARY

Continued cup-burner, laboratory-scale discharge, and field-scale testing is crucial to halon alternatives development. The laboratory-scale testing allows for screening of chemicals before field testing, thus saving time and money. Flow calculations and standardization validate the laboratory work before continuing to larger (field-scale) testing. Small-, medium-, and large-scale testing is an intermediate step between the laboratory and full-scale field tests. The complete NMERI test results for the efforts described here will soon be published and available through the National Technical Information Service (NTIS).

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