AN UPDATE ON NMERI CUP-BURNER TEST RESULTS

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INTRODUCTION

One of the most widely used apparatuses for testing candidate replacements for Halons 1301 and 1211 is the cup burner. Originally developed by Imperial Chemical Industries (ICI) in 1970 and refined in 1973,' the cup burner is the standard flame extinguishment test technique accepted by the National Fire Protection Association (NFPA).[2]

Since 1985, the Center for Global Environmental Technologies (CGET), within the New Mexico Engineering Research Institute (NMERI) at The University of New Mexico has been developing technical options to halon fire extinguishing agents.' Halons are believed to contribute to the depletion of the earth's stratospheric ozone layer and were phased out of production (for all but "essential" uses) at the end of 1993. As part of the our research efforts on one option, chemical replacements, NMERI/CGET has developed three cup burners based upon the ICI burner — the NMERI full-scale, 5/8-scale, and 2/5-scale burners" — and has performed extensive laboratory-scale cup-burner extinguishment concentration measurements. An overview of cup-burner concentration values obtained is given here. Some of these measurements have been reported previously;[4,5,6] however, here they have been refined and additional values have been added. Also, values for various fuels, altitude, and heated fuel effects are presented.

The cup-burner apparatus consists of a glass chimney containing a small glass flame cup filled with a liquid fuel or containing a central burner for a gaseous fuel. Measured amounts of extinguishing agent and air enter the bottom of the chimney, are mixed, and allowed to pass by the ignited fuel. The amount of extinguishing agent is increased until the flame is extinguished, and the percent (molar, gas volume) concentration of agent is calculated. Generally, five to ten individual extinguishment values for each compound tested are averaged together to obtain the reported cup-burner value (extinguishment concentration).

CUP-BURNER TESTING

All numerical data reported in tables here (unless otherwise specified) are taken from the **NMERI** 5/8-scale cup burner (Figure 1) using n-heptane fuel. At **NMERI,** different cup-burner test configurations (methods) are used depending on the boiling point of the material tested. Agents that are gases at room temperature are removed directly from bulk cylinders and the agent flow is monitored with gas and bubble flowmeters, as shown in Figure 2. Agents with boiling points near and significantly above room temperature ("liquid" agents) are metered with a discharge cylinder, needle valve, and an electronic scale with computer data acquisition (Figure **3).** The extinguishment concentrations of agents that have boiling points near room temperature (approximately 25 ± 10°C) or those which are blends of different compounds are difficult to measure. Such materials do not vaporize well into the cup-burner. Results obtained by this method are not **as** precise as those provided by other methods.

To validate the extinguishment concentrations obtained by these testing procedures, an extensive study of the experimental variables that affect the accuracy and precision of cup-burner results has been performed. The study includes an analysis of flow measurement errors and a determination of the sensitivity of extinguishment concentrations to these errors. Analysis of measurement and calculation techniques indicate that errors inherent in the measurement of air and agent flow rates and times are the most critical in determining the precision of the extinguishment concentration. A series of measurements have been made to determine the magnitude of these errors, and the results are presented in Table **1. Error** propagation calculations give **95** percent confidence limits of **10.1** percent (gases) and **17.9** percent (liquids) of the extinguishment concentration reported. These values correspond to standard deviations of 5.0 percent and **8.8** percent, respectively.

CUP-BURNER TEST RESULTS

Average extinguishment concentrations measured in the **NMERI** 5/8-scale cup burner for the materials tested are presented in Table 2 and **3.** The values presented in Table 2 have been scrutinized for possible experimental errors, suitability for testing with available methods, flammability, and other factors which might affect the reported values. The values reported in this table have met all the criteria required for full confidence subject to the limitations presented above. The values presented in Table **3** are for various reasons (e.g., flammability, limited quantities, boiling point near room temperature, questionable experimental conditions) felt to be

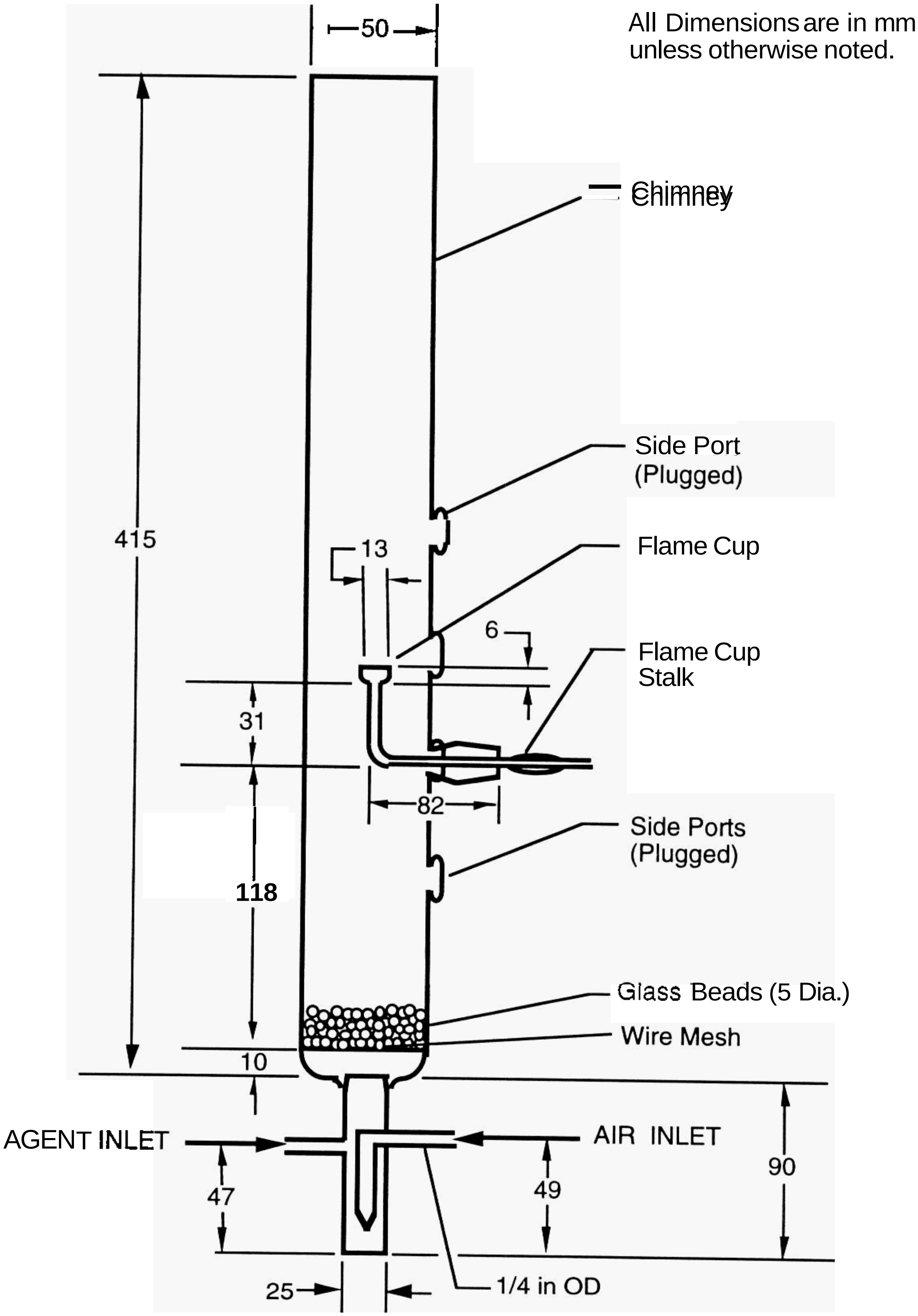

Figure **1.** NMERI 5/8-scale cup burner.

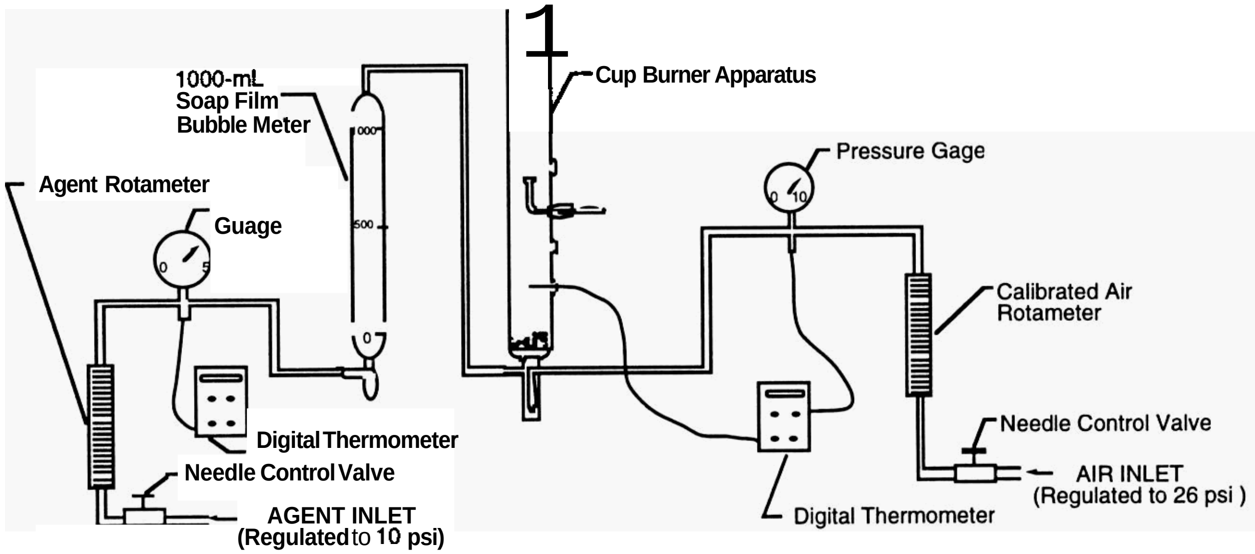

Figure 2. Gaseous agent cup-burner test configuration.

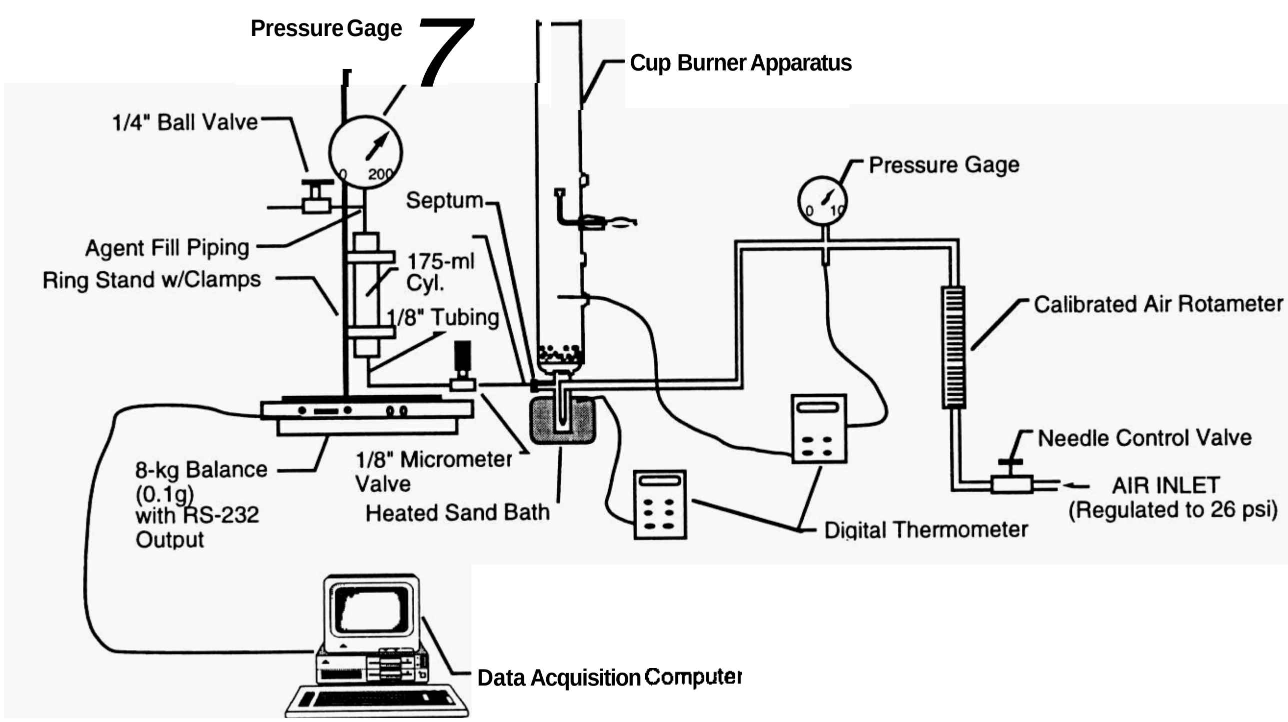

Figure 3. Liquid agent cup-burner test configuration.

TABLE 1. EVALUATION OF MEASUREMENT ERRORS IN CUP BURNER EXPERIMENTS.

Measurement	Number of Samples	Mean Value, Umin	95 Percent Confidence Limit (2 a),mL/min
Air Flow	43	7322	±655 (8.9%)
Agent Flow (gas)			
High Rate	12	1494	f35 (2.3%)
Intermediate Rate	12	1001	f14 (1.4%)
Low Rate	12	496	±11 (2.2%)
Agent Flow (liquid)			
High Rate	10	3.73	±0.22 (5.9%)
Low Rate	10	2.44	fo.18(7.4%)

of lower reliability and are presented for completeness only. Table **4** contains results **for** additional materials determined after the Full Confidence values were analyzed. Though the results in this table have not received the same analysis that the Full Confidence values received, they **are** believed to be equally reliable.

INTERLABORATORY COMPARISON

In an expansion of work reported earlier? a survey of literature and industry allows a comparison of cup burner extinguishment concentrations for several organizations (Table ***5).*** These organizations are the Naval Research Laboratory (NRL), Great Lakes Chemical Company (Great Lakes), Imperial Chemical Industries (ICI), University of Tennessee (Univ. Tenn.), Fenwal Safety Systems (Fenwal), and 3M. Most of these data were obtained from personal communications, some are reported in NFPA 2001.[2] The NMERI values for the halocarbons are taken from Table ***2.*** The average deviations in Table ***5*** are given as percentages of the mean values. Analysis **of** these data indicates that, despite the differences in cup burner design and variations in test techniques, extinguishment values for compounds agree well between laboratories. The agreement is generally within ± 5 to 10 percent, which is approximately the same variability **as** predicted from the error analysis.

EXTINGUISHING CONCENTRATIONS FOR VARIOUS AGENTS WITH VARIOUS FUELS

The cup-burner extinguishment concentrations **for** various halocarbon agents and fuels **are** presented in Table ***6.*** Extinguishment concentrations for various fuels tested in conjunction with inert agents are presented in Table 7. Extinguishment concentrations from other organizations are also presented in these tables.

TABLE 2. FULL CONFIDENCE CUP BURNER EXTINGUISHMENT CONCENTRATIONS.

Halocarbon No.	Halon No.	IUPAC Name	CAS No.	Exting. Conc., vol. %
10	104	Tetrachloromethane(carbon tetrachloride)	56-23-5	7.6
11	113	Trichlorofluoromethane	75-69-4	7.8
12	122	Difluorodichloromethane	75-71-8	7.6
12B1	1211	Bromochlorodifluoromethane (Halon 1211)	353-59-3	3.2
12B2	1202	Dibromodifluoromethane	75-61-6	2.2
13	131	Chlorotrifluoromethane	75-72-9	7.3
13B1	1301	Bromotritluoromethane(Halon 1301)	75-63-8	2.9
13I1	13001	Tritluoroiodomethane(CF_3I, Triodide™, Iodoguard™)	2314-97-8	3.0
14	14	Tetrafluoromethane	75-73-0	13.8
20	103	Trichloromethane	67-66-3	10.5
21B2	1102	Dibromofluommethane	1868-53-7	1.8
22	121	Chlorodifluoromethane	75-45-6	11.6
22B1	1201	Bromodifluoromethane (FM-100™)	1511-62-2	4.4
23	13	Trifluoromethane (FE-13™)	75-46-7	12.6
30	102	Dichloromethane	75-09-2	14.1
30B1	1011	Bromochloromethane	74-97-5	2.7
30B2	N/A	Dibromomethane	74-95-3	1.3
32	12	Difluoromethane	75105	8.8
113	233	1,2,2-Trichloro-1,1,2-trifluoroethane	76-13-1	6.2
113a	233	1,1,1-Trichloro-2,2,2-trifluoroethane	354-58-5	6.2
114	242	1,2-Dichloro-1,1,2,2-tetrafluoroethane	76-14-2	6.4
114a	242	1,1-Dichloro-1,2,2,2,-tetrafluoroethane	374-07-2	6.4
114B2	2402	1,2-Dibromo-1,1,2,2-tetrafluoroethane	124-73-2	2.1
115	251	1-Chloro-1,1,2,2,2-pentafluoroethane	76-15-3	6.3
115I1	25001	Pentafluoroiodoethane	354-64-3	2.1
116	26	Hexafluoroethane	76-164	7.8
122	223	1,1-Difluoro-1,2,2-trichloroethane	354-21-2	6.3
122a	223	1.1,2-Trichloro-1,2,-difluoroethane	354-15-4	6.3
123B1	2311	2-Bromo-2-chloro-l ,1.1-trifluoroethane	151-67-1	3.1
123B2	2302	2,2-Dibromo-1,1,1-trifluoroethane	354-30-3	1.9
123aB2	2302	1,2-Dibromo-1,1,2-trifluoroethane	354-04-1	2.0
123aB1α	2311	1-Bromo-2-chloro-1,1,2-trifluoroethane	354-06-3	3.2
124	241	2-Chloro-1.1,1,2-tetrafluoroethane (FE-241™)	2837-89-0	6.7
124B1	2401	2-Bromo-l,1,1,2-tetrafluoroethane	124-72-1	2.9
125	25	Pentafluoroethane(FE-25™)	354-33-6	9.4
132b	222	1,2-Dichloro-1,1-difluoroethane	1649-08-7	7.9
133a	231	2-Chloro-1,1,1-trifluoroethane	75-88-7	7.6
134	24	1,1,2,2-Tetrafluoroethane	359-35-3	11.2
134a	24	1,1,1,2-Tetrafluoroethane	811-97-2	10.5
141	212	1,2-Dichloro-1-fluoroethane	430-57-9	18.7
142B1	2201	2-Bromo-1,l-difluoroethane	359-07-9	4.2

TABLE 2. FULL CONFIDENCE CUP BURNER EXTINGUISHMENT CONCENTRATIONS (Cont'd).

Halocarbon No.	Halon No.	Name	CAS No.	Exting. Conc., vol. %
150a	202	1,1-Dichloroethane	75-34-3	8.6
217bal1	37001	Heptafluoro-2-iodopropane	677-69-0	3.2
217cal1	37001	Heptafluoro-1-iodopropane	754-34-7	3.0
218ca	38	Octafluoropropane(CEA-308™)	76-19-7	6.1
225ca/cb	352	3,3-Dichloro-1,1,1,2,2-pentafluoropropane/1,3-Dichloro-1,1,2,2,3-pentafluoropropane (azeotrope)	127564-92-5	6.5
227ea	37	1,1,1,2,3,3,3-Heptafluoropropane (FM-200™)	431-89-0	6.3
227cb	37	1,1,1,2,2,3,3-Heptafluoropropane	2252-84-8	6.5
236ea	36	1,1,1,2,3,3-Hexafluoropropane	431-63-0	6.6
236fa	36	1.1,1,3,3,3-Hexafluoropropane (FE-36™)	690-39-1	5.6
245cb	35	1,1,1,2,2-Pentafluoropropane	1814-88-6	8.2
254cb	34	1,1,2,2-Tetrafluoropropane	40723-63-5	10.1
318	48	Octafluorocyclobutane	115-25-3	7.2
31911	49001	Nonafluoro-1-iodobutane	423-39-2	2.8
1233xfB1	NIA	2-Bromo-3.3.3-trifiuoropropene	1514-82-5	2.6
1242zfB1	NIA	3-Bromo-3,3-difluoropropene	420-90-6	4.5
134381	N/A	4-Bromo-3-chloro-3,4,4-trifluoro-1-butene	374-25-4	4.5
1344B1	NIA	4-Bromo-3,3,4,4-tetrafluoro-1-butene	18599-22-9	3.5
3-1-10	4-10	Decafluorobutane (perfluorobutane) (CEA-410™)	355-25-9	5.0
3181ccl2	48002	Octafluoro-1,4-diiodobutane	375-50-8	2.1
4-1-12	5-12	Dodecafluoropentane	678-26-2	4.5
51-13αl1	6-13-001	Tridecafluoro-l-iodohexane	355-43-1	2.5
5-1-14	6-14	Tetradecafluorohexane(perfluorohexane) (CEA-614™)	355-42-0	4.4
6-1-16	7-16	Hexadecafluoroheptane(perfluoroheptane)	355-57-9	4.0
7-1-171I1	8-17-0-0-1	Heptadecafluoro-1-iodooctane	507-63-1	1.9
7-1-18	8-18	Octadecafluoro-octane	307-34-6	3.8
NIA	N/A	Perfluoromethylcyclopentane	18022-7	3.7
N/A	NIA	Perfluoromethylcyclohexane	355-02-2	3.5
NIA	N/A	Trifluoro(trifluoromethyl)oxirane	428-59-1	9.3
NIA	NIA	1,3-Bis(trifluoromethyl)decafluorocyclohexane	335-27-3	3.2
N/A	NIA	Fluorocyclotriphosphazene, Chlorofluorocycletriphosphazene	N/A	0.6

TABLE 3. AVERAGE CUP BURNER EXTINGUISHMENT CONCENTRATIONS OF LIMITED CONFIDENCE.

Halocarbon No.	Halon No.	Name	CAS No.	Exting. Conc., vol. %
31	111	Chlorofluoromethane	593-70-4	20.0 ††
121	214	1-Fluoro-1,1,2,2-tetrachloroethane	354-14-3	7.8 **
123	232	2,2-Dichloro-1,1,1-trifluoroethane (FE-232™)	306-83-2	7.1 *
123a	232	1,2-Dichloro-1,1,2-trifluoroethane	354-23-4	8.3 *
130a	204	1,1,1,2-Tetrachloroethane	630-20-6	8.0 ††
141b	212	1,1-Dichloro-1-fluoroethane	1717-00-6	12.5 *†
216ba	362	1,2-Dichloro-1,1,2,3,3,3-hexafluoropropane	661-97-2	4.9 *
270da	302	1.2-Dichloropropane	78-87-5	4.6 †
270fa	302	1,3-Dichloropropane	142-28-9	5.5 †
272ea	32	1,2-Difluoropropane	62126-90-3	5.6 †
1233zdB1	NIA	1-Bromo-3,3,3-trifluoropropene	NIA	8.5
7-1-17αB1	8-17-0-1	1-Bromo-heptadecafluoro-octane	423-55-2	2.4
11-1-18	10-18	Perfluorodecalin	30694-5	3.6
NIA	NIA	1-Bromo-3,3,3-trifluoro-1-propene	NIA	8.5 **
N/A	N/A	Chloropentafluorobenzene	344-07-0	5.4
NIA	NIA	1,3-Dichloro-2,4,5,6-tetrafluorobenzene	1198-61-4	6.0

* Near room temperature boiling point.
** Insufficient quantity for accurate testing.
† Flammable compound.
†† Questionable expenmental conditions.

TABLE 4. ADDITIONAL AVERAGE CUP BURNER EXTINGUISHMENT CONCENTRATIONS.

Halocarbon No.	Halon No.	Name	CAS No.	Exting. Conc.. vol. %
NIA	NIA	Argon	7440-37-1	38
NIA	N/A	Argonite™ (50% N_2/50% Ar)	NIA	29
NIA	N/A	Carbon Dioxide	124-38-9	20
NIA	NIA	Nitrogen	7727-37-9	30
NIA	N/A	HCFC Blend A (NAF S-III) --Additive plus the following compounds:	NIA	9.9
22	121	Chlorodifluoromethane	7545.6	
123	232	2,2-Dichloro-1,1.l-trifluorethane	306-83-2	
124	241	2-Chloro-1,1,1,2-tetrafluoroethane	2837-89-0	
NIA	N/A	3-Bromo-3.3-difluoro-1-propene	420-90-6	4.5
NIA	NIA	2-Bromo-3,3,3-trifluoro-1-propene	1514-82-5	2.1
HCC-280fa	301	1-Chloropropane	540-54-5	3.3
HCC-280da	301	2-Chloropropane	75-29-6	3.2

TABLE 5. INTERLABORATORY COMPARISON OF n-HEPTANE CUP BURNER EXTINGUISHMENT CONCENTRATIONS.

Agent	[a]NMERI	[a]NRL	'Great Lakes	[a,b]MS Eng.	'Univ. Tenn.	'Fenwal	[a]3M	'Mean	Average Deviation,%
HFC-23	12.6	12	12.7	---	12.6	12.0	12.9	12.5	3.0
HCFC-124	*6.7*	---	---	---	---	6.4	---	*6.6*	3.2
HFC-125	9.4	8.8	9.3	---	---	8.1	---	8.9	6.7
FC-3-1-10	5.0	5.2	4.1	4.7	5.7	5.5	5.9	5.2	12.3
FC-5-1-14	4.4	---	---	4.2	---	4.4	4.0	4.3	5.4
Halon 1211	3.2	3.6	3.3	---	3.5	3.8	---	3.6	8.4
Halon 1301	2.9	3.1	3.5	---	2.7	3.0	3.9	3.3	15.4
HFC-227ea	6.3	*6.6*	5.9	6.0	---	---	7.5	*6.6*	10.3
HBFC-22B1	4.4	4.1	3.9	---	---	3.9	---	4.2	7.5
N_2	30	30	---	31	---	---	---	30	0.0
CO_2	20.4	21	---	---	---	28	---	23	16.4

[a]Values are volume % concentrations. [b]Mainstream Engineering Corp., personal communications Larry Grzyll, June 1996.

ATMOSPHERIC PRESSURE EFFECTS ON CUP BURNER CONCENTRATIONS

The effect of atmospheric pressure on extinguishment concentration was tested by transporting the NMERI 5/8-scale cup-burner apparatus to Vancouver, B.C., Canada, which has an atmospheric pressure of 760 mm Hg (sea level). In Vancouver, tests were run with combinations of fuels and agents that already had previously determined extinguishment concentrations determined in Albuquerque, NM, USA, which has an atmospheric pressure of 630 mm Hg (5280 ft above sea level). The fuels that were tested in combination with HCFC-Blend A (NAF S-III) were heptane, isopropyl alcohol, methanol, acetone, and toluene. Similarly, HCFC-124, Halon 1211, HCFC-22, and HFC-134a were also tested with heptane as the fuel. For each combination of fuel and agent, at least five tests were run and the average extinguishment concentration was calculated. In each of these tests, the agent was in the liquid phase, and the liquid-filled cylinder was placed on a scale. A data acquisition computer program was used that utilized changes in the scale reading as the agent is discharged and time in order to determine the agent flow rate into the cup-burner apparatus (Figure **3).**

The comparison of the tests run at different altitudes (atmospheric pressures) is presented in Table 8. The slight differences in the extinguishment concentration for the test runs at different altitudes are within the range of experimental error expected in the cup-burner tests. There was very little change in the extinguishment concentration for the test runs at different altitudes.

TABLE 6. CUP BURNER EXTINGUISHMENT CONCENTRATIONS FOR VARIOUS FUELS.

Fuel	HCFC-Blend A (NAF S-III) (NMERI)	HCFC-Blend C (NAF P-III) (NMERI)	HCFC-124 (FE-241) (NMERI)	HFC-227ea (FM-200) (Great Lakes)	HFC-227ea (FM-200) (3M)	FC-3-1-10 (CEA-410) (3M)
Acetone	9.5	---	---	6.8	7.1	5.5
Acetonitrile	7.0	---	---	3.7	---	---
AV Gas	11.4	---	---	6.7	---	5.0
Benzyl Alcohol	---	---	---	---	5.8	5.5
Butanol	12.2	---	---	7.1	7.9	6.7
Butyl Acetate	9.8	---	---	6.6	---	---
Cyclohexane	9.9	---	---	---	7.0	5.5
Cydohexanone	10.3	---	---	---	---	---
Cyclopentanone	---	---	---	6.7	---	---
Diesel No. 2	9.6	5.6	6.8	6.7	---	---
Ethane	---	---	---	7.5	---	---
Ethanol	11.0	---	---	8.1	8.7	6.8
Ethyl Acetate	10.6	---	---	5.6	---	---
Ethylene Glycol	11.4	---	---	7.8	---	---
Gas (unleaded, 7.8% Ethanol)	9.8	6.9	7.6	6.5	---	---
Heptane	9.9	6.4	6.7	5.8	7.5	5.9
Hexane	10.9	---	---	---	7.2	5.6
Hydraulic Fluid No. 1	9.6	---	---	5.8	---	---
Hydrogen	20.1	---	---	---	---	---
Isoctane	9.8	---	---	---	6.5	5.5
Isopropanol	10.6	---	---	7.3	7.7	6.2
Jet A	---	6.1	---	---	---	---
JP-4	10.2	5.7	7.2	6.6	6.9	5.0
JP-5	9.0	---	7.5	6.6	---	---
Methane	13.7	---	---	6.2	---	---
Methanol	15.1	---	---	10.0	10.1	9.4
Methyl Ethyl Ketone	---	---	---	6.7	---	5.9
Methyl Isobutyl Ketone	9.4	---	---	6.6	---	5.5
Morpholine	13.7	---	---	7.3	---	---
Natural Gas	12.4	---	---	---	---	---
Nitromethane	---	---	---	10.1	---	---
Propane	12.6	---	---	6.3	---	---
Pyrollidine	10.1	---	---	7.0	---	---
Tetrahydrofuran	12.0	---	---	7.2	---	---
Toluene	7.0	---	---	5.8	5.5	4.2
Transformer Oil	---	---	---	6.9	---	---
Turbo Hydraulic Oil 23	---	---	---	5.1	---	---
Xylene	8.7	---	---	5.3	---	---

TABLE 6. CUP BURNER EXTINGUISHMENT CONCENTRATIONS FOR VARIOUS FUELS (Cont'd).

Fuel	HFC-23 (FE-13) (Others)	HFC-23 (FE-13) (Du Pont)	CF_3I (NMERI)	Halon 1301 (NFPA 12A and Others)	Halon 1301 (NMERI)
Acetone	11.3	12.0	---	3.3	---
Acetonitrile	---	---	1.7	1.7	1.5
AV Gas	---	---	3.7	---	2.8
Benzyl Alcohol	---	---	---	---	---
Butanol	---	---	3.3	---	3.7
Butyl Acetate	---	---	2.5	---	2.5
Cyclohexane	---	---	---	---	---
Cyclohexanone	---	---	---	---	---
Cydopentanone	---	---	---	---	3.7
Diesel No. 2	---	---	3.3	---	2.6
Ethane	---	---	---	---	---
Ethanol	---	---	3.0	3.8	3.0
Ethyl Acetate	---	---	3.0	3.0	1.9
Ethylene Glycol	---	---	2.4	---	1.9
Gas (unleaded. 7.8% Ethanol)	---	---	3.6	---	3.5
Heptane	12.9	12.0	3.0	4.1	2.9
Hexane	---	---	---	---	---
Hydraulic Fluid No. 1	---	---	2.3	---	2.0
Hydrogen	---	---	---	---	---
Isoctane	---	---	---	---	---
Jet A	---	---	---	---	---
JP-4	---	---	3.3	---	2.8
JP-5	---	---	3.2	---	2.6
Methane	---	---	2.0	3.1	2.3
Methanol	---	16.3	3.8	---	5.9
Methyl Ethyl Ketone	---	---	4.4	---	2.6
Methyl Isobutyl Ketone	---	---	2.9	---	2.4
Morpholine	---	---	---	---	3.9
Natural Gas	---	---	---	---	---
Nitromethane	---	---	---	---	---
Propane	---	---	3.0	4.3	2.8
Pyrollidine	---	---	2.8	---	2.9
Tetrahydrofuran	---	---	---	---	3.6
Toluene	10.0	9.2	---	---	---
Transformer Oil	---	---	---	---	---
Turbo Hydraulic Oil 23	---	---	---	---	2.2
Xylene	---	---	---	5.5	1.7

TABLE 7. INERT GAS EXTINGUISHMENT CONCENTRATIONS FOR VARIOUS FUELS.

Fuel	IG-541 (INERGEN) (HRC Values)	Argon	IG-55 Argonite** (50% N_2, 50% Ar) (NMERI)
Acetone	31	30	26
Acetonitrile	27	15	19
AV Gas	36	29	25
Benzyl Alcohol	---	---	---
Butanol	37	32	27
Butyl Acetate	---	---	26
Cyclohexane	---	32	28
Cyclohexanone	---	29	25
Cydopentanone	42	---	---
Diesel No. 2	---	25	22
Ethane	30	---	---
Ethanol	35	32	28
Ethyl Acetate	33	31	27
Ethylene Glycol	42	27	27
Gas (unleaded, 7.8% Ethanol)	---	30	25
Heptane	29	38	28
Hexane	34	33	28
Hydraulic Fluid No. 1	---	19	20
Hydrogen	---	---	---
Isoctane	---	27	25
Isopropanol	31	28	25
JP-4	---	31	29
JP-5	---	30	24
Methane	15	29	27
Methanol	44	38	34
Methyl Ethyl Ketone	36	---	---
Methyl Isobutyl Ketone	32	---	---
Morpholine	---	35	28
Natural Gas	---	---	---
Nitromethane	---	36	34
Propane	32	35	33
Pyrollidine	---	---	30
Tetrahydrofuran	---	---	33
Toluene	31	27	24
Transformer Oil	---	---	---
Turbo Hydraulic Oil 23	---	---	26
Xylene	---	24	21

TABLE 8. CUP-BURNER TESTS RUN AT DIFFERENT ALTITUDES (ATMOSPHERIC PRESSURES).

Agent	Fuel	Ext. Conc., vol %, at 760 Mm Hg (1 atm)	Ext. Conc., vol %. at 630 Mm Hg (0.83 atm)	Difference. vol %	% error
HCFC-Blend A	heptane	9.8	9.9	0.1	1.0
HCFC-Blend A	isopropyl alcohol	10.6	10.8	0.2	1.8
HCFC-Blend A	methanol	16.3	15.1	1.2	7.9
HCFC-Blend A	acetone	10.5	9.5	1.0	11
HCFC-Blend A	toluene	7.8	7.0	0.8	11
HCFC-124	heptane	6.4	6.7	0.3	4.5
Halon 1211	heptane	3.1	3.2	0.1	3.1
HCFC-22	heptane	10.4	11.6	1.2	10
HFC-134a	heptane	10.4	10.5	0.1	1.0

FUEL TEMPERATURE EFFECTS ON CUP BURNER EXTINGUISHMENT CONCENTRATIONS

The effect of fuel temperature on the extinguishment concentration was analyzed by performing tests with the fuels at room temperature and also at temperatures fairly close to the boiling point of the fuel. For a particular test, the fuel was heated by wrapping heat tape around the tubing leading to the fuel cup. The temperature of the heat tape was controlled by a variable transformer and temperature controller. A thermocouple was fed through the fuel tubing into the fuel cup to monitor the fuel temperature (Figure 4). The tested fuels were heptane, diesel, and JP-5. The agents used in this test series were HFC-227ea (FM-200) and HCFC-Blend A (NAF S-III).

Table 9 presents the results of the heated fuel tests. The tests run with HFC-227ea and HCFC-Blend **A** as the agents, and heptane, hexane, and diesel as the fuel did not show significant difference in extinguishment concentration with changes in the fuel temperature. However. small increases were observed for **JP-5.**

TABLE 9. CUP-BURNER TESTS FOR HEATED FUELS.

Agent	Fuel	Fuel Temp, °C	Ext. Conc., vol %	‘Previously Reported NMERI Ext. Conc., vol %	Difference, vol %	% Difference from Previously Reported Value, %
HCFC-Blend A	heptane	2 2	10.1	9.9	0.2	2.0
HCFC-Blend A	heptane	50	9.9	9.9	0.0	0.0
HCFC-Blend A	heptane	65	10.1	9.9	0.2	2.0
HCFC-Blend A	hexane	2 2	11.2	10.9	0.3	2.8
HCFC-Blend A	hexane	50	11.8	10.9	0.9	8.3
HCFC-Blend A	diesel	70	11.3	9.6	1.7	1.8
HCFC-Blend A	JP-5	70	11.4	9.0	2.4	27
HFC-227ea	heptane	2 2	5.8	6.3	0.5	7.9
HFC-227ea	heptane	50	5.8	6.3	0.5	7.9
HFC-227ea	heptane	65	5.8	6.3	0.5	7.9
HFC-227ea	diesel	70	6.7	6.7	0.0	0
HFC-227ea	JP-5	70	7.3	6.6	0.7	11

‘Room Temperature

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