"BEST VALUES" OF CUP-BURNER EXTINGUISHING CONCENTRATIONS

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INTRODUCTION

In March 1997, the National Fire Protection Association (NFPA) Technical Committee on Halon Alternative Protection Options established the NFPA Standard 2001 Cup Burner Data **Task** Group. The Task Group's mandate is to (1) assess cup-hurner data for all agents in or proposed for the NFPA 2001 Standard [1]; (2) determine whether meaningful "best values" can be deduced; (3) determine what data (if any) should go into the next edition of the Standard; and (4) establish procedures for future submission of cup burner data for to the NFPA 2001 committee. This paper presents tlic cup-burner extinguishment data collected and assessed to date by the Tusk Group.

DATA COLLECTION AND ASSESSMENT

To date, the Task Group has reviewed data submitted by the following organizations for 323 agent/fuel combinations, each data point represented an average of 2 to 35 determinations.

- 3M Company, St. Paul, Minnesota, USA
- Ansul Incorporated, Marinette. Wisconsin. USA
- Kidde-Fenwal, Inc., Ashland, Massachusetts, USA
- Koatsu Company Ltd., Itami, Hyogo, Japan
- Mainstream Engineering Corporation, Rockledge, Florida, USA
- National Institute of Standards and Technology, Gaithersburg, Maryland, USA
- National Research Institute of Fire and Disaster, Tokyo, Japan
- New Mexico Engineering Research Institute, Albuquerque, New Mexico, USA
- US Naval Research Laboratory, Washington, DC. USA
- Verband der Schndenversicherer e.V., Köln, Germany

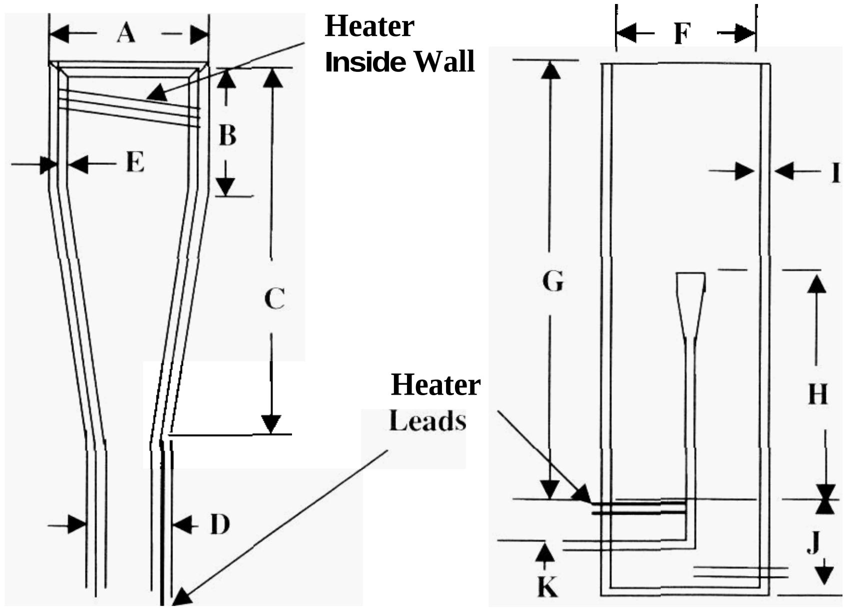
Of these 323 agent/fuel combinations, 263 werc for the thirteen agents in the NFPA 2001 Standard [1] or proposed for future editions of this standard (Tablc 1). The data review resulted in selection of 158 "best values" for cup-burner extinguishing concentrations. which included the fuels shown in the following list. The "best values" include no data from apparatuses differing significantly from that being considered for the International Standards Organization (ISO) standard on gaseous fire extinguishing agents [2} and for future editions of the NFPA 2001 standard (Figurc 1) except where no other data are available. Although both the NFPA planned standard and the ISO draft standard require a fuel temperature of 25 ± 1 °C, the Task Group accepted data for fuel temperatures of 25 ± 5 °C and. where no fuel temperature was given. took the reported air temperature as the fuel temperature. These variations were made to obtain sufficient data for evaluation. It is believed that these deviations are unlikely to cause significant variations. To date, no data submitted to the Cup Burner Data Task Group have niet the proposed ISO or NFPA standard requirements for both apparatus and method.

TABLE 1. AGENTS IN OR PROPOSED FOR NFPA STANDARD 2001.

Agent	Formula	Chemical Name
FC-218	$CF_3CF_2CF_3$	octafluoropropane
FC-3-1-10	$CF_3CF_2CF_2CF_3$	decafluorobutane
FIC-13I1	CF_3I	trifluoroiodomethane
HCFC Blend A		
82% HCFC-22	$CHClF_2$	chlorodifluoromethane
9.5% HCFC-124	$CHClFCF_3$	2-chloro-1,1,1,2-tetrafluoroethane
4.75% HCFC-123	$CHCl_2CF_3$	2,2-dichloro-1,1,1-trifluoroethane
3.75% additive	$C_{10}H_{16}$	isopropenyl-1-methylcyclohexene
HCFC-124	$CHClFCF_3$	2-chloro-1,1,1,2-tetrafluoroethane
HFC-125	CHF_2CF_3	pentafluoroethane
HFC-227ea	CF_3CHFCF_3	1,1,1,2,3,3,3-heptafluoropropane
HFC-23	CHF_3	trifluoromethane
HFC-236fa	$CF_3CH_2CF_3$	1,1,1,3,3,3-hexafluoropropane
IG-01	Ar	argon
IG-100	N_2	nitrogen
IG-541		
52% N_2	N_2	nitrogen
40% Ar	Ar	argon
8% CO_2	CO_2	carbon dioxide
IG-55		
50% N_2	N_2	nitrogen
50% Ar	Ar	argon

List of fuels for which at least some "best values" have been determined:

70% isopropanol in water
80% MeOH/20% n-heptane
acetone
acetonitrile
aviation gas, 100 octane
benzene
carbon disulfide
cyclohexane
diesel
diesel no. 2
diethyl ether
ethanol
ethyl acetate
ethylene glycol
Exxon Turbo Oil
gasoline (unleaded)
heptane (commercial)
hydraulic oil (Mobil 350)
hydrogen
isobutanol
isooctane
isopropanol
Jet A/JP-5
JP-4
kerosene
methane
methanol
methyl isobutyl ketone
morpholine
n-butanol
n-butyl acetate
n-decane
n-dodecane
n-heptane
n-hexane
n-octane
n-pentane
n-propanol
n-undecane
natural gas
nitromethane
propane
pyrrolidine
tetrahydrofuran
toluene
transformer oil
xylene



Cup		Chimney with Cup	
Outside diameter **(A):**	28-31 mm	Inside diameter (F):	85 ± 2 mm
Taper height (C):	70 ± 3.5 mm	**Cup** placement (H):	235±11.75 mm
Wall thickness (E):	1-2 mm	**Diffuser** height (J)	90 ± 4.5 mm
Height (B):	25 ± 1.25 mm	Height (G):	533 ± 26.65 mm
Stem outside diameter (D):	12 ± 0.6 mm	Wall thickness (I):	2-5 mm
Lip chamfer (bevel):	45 deg	Fuel line to diffuser **top** (K):	36 ± 1.8 mm

Figure 1. Proposed standard cup burner with dimensions.

RESULTS

Table *2* (which includes Halon 1301 data for comparison) gives the "best values" for cup-burner concentrations in percent by volume (vol.%) with the standard deviations (where there is more than one sourcc) and, in parentheses, the number of sources. The standard deviations give only the data variation between sources and do not include the scatter among the individual determinations averaged to give the data submitted. **As** noted earlier, where data were available for any agent/fuel combination from both cup burners near that proposed in the draft ISO and **NFPA** standards, and non-standard cup burners, only the former data were used. Where non-standard cup-burncr data were available. these were used; such data are indicated by a footnote.

The draft ISO and proposed NFPA standards require that extinguishment concentrations be determined at increasing air flow rates until a platcau is reached whcre there is no furthcr increasc in extinguishment concentration. Despite this requirement. there is evidence that over **a** wide range of air tlow rates, thcsc Concentrations are invariant [3]. Nevertheless, the cup-burner extinguishment concentrations determined using the newer "plateau" procedure appear to be higher than earlier values in the only two cases where comparisons are possible. In Table 3. the number of determinations are enclosed in parentheses; brackets denote the air flow rates in L/min. An increase in extinguishment concentration would be expected were the plateau method to give a worse-case extinguishment concentration. The differences are, however, small and the number **of** comparisons, very limited. Nevertheless, values determined by the plateau method are separated and given in brackets (Table *2)*.

TABLE 2. “BEST VALUES” OF CUP-BURNER CONCENTRATIONS, VOL.%.

Fuel	Halon 1301	FC-218	FC-3-1-10
70% isopropanol in water			
80% methanol/20% n-heptane	5.8 (1)[a]		
acetone		[6.3 (1)]	[5.2 (1)]
acetonitrile			
aviation gas, 100 octane, low lend			
benzene	2.4 (1)		3.4 (1)
carbon disulfide			
cyclohexane			
diesel			
diesel no. 2			
diethyl ether			
ethanol	4.3 ± 0.0 (2)		6.9 ± 0.0 (2)
ethyl acetate			
ethylene glycol			
Exxon Turbo Oil			
gasoline (unleaded)			
heptane (commercial)	3.2 (1)		
hydraulic oil (Mobil Fluid 350)			
hydrogen			
isobutanol			
isooctane			
isopropanol			
Jet A/JP-5			
JP-4			
kerosene	3.4 (1)		5.0 (1)
methane			
methanol	7.8 (1)		8.0 (1)
methyl isobutyl ketone			
morpholine			
n-butanol			
n-butyl acetate			
n-decane	3.9 (1)		
n-dodecane	3.7 (1)		
n-heptane	3.4 ± 0.0 (2)	6.1 (1)[a]; [6.5 (1)]	5.3 ± 0.0 (2) [5.5 (1)]
n-hexane			
n-octane	3.4 (1)		
n-pentane			
n-propanol			
n-undecane			
natural gas			
nitrornethane			
propane			
pyrrolidine			
tetrahydrofuran			
toluene	2.3 ± 0.0 (2)		3.6 ± 0.0 (2)
transformer nil	2.3 (1)		5.4 (1)
xylene			

[a] Nonstandard cup burner.

TABLE 2. "BEST VALUES" OF CUP-BURNER CONCENTRATIONS. VOL.%. (cont.).

Fuel	FIC-13I1	HCFC Blend A	HCFC-I24
70% isopropanol in water			
80% methanol/20% *n*-heptane			
acetone		10.0 ± 0.7 (2)[a]	
acetonitrile		7.0 (1)[a]	
aviation gas, 100 octane, low lead		11.4f0.1 (2)[a]	
benzene			
carbon disulfide			
cyclohexane		10.1 ± 0.3 (2)[a]	
diesel			6.8 (1)[a]
diesel no. 2		9.6 (1)[a]	
diethyl ether			
ethanol			
ethyl acetate		10.6 (1)[a]	
ethylene glycol		11.1 (1)[a]	
Exxon Turho Oil			
gasoline (unleaded)		'1.7 (1)[a]	7.5 (1)[a]
heptane (commercial)			
hydraulic oil (Mobil Fluid 350)			
hydrogen		20 (1)[a]	
isobutanol			
isooctane		9.8 (1)[a]	
isopropanol		10.6(1)[a]	
Jet A/JP-5		0.0 (1)[a]	6.9 (1)[a]
JP-4		10.1 (1)[a]	
kerosene			
methane		13.7 (1)[a]	
methanol		16 ± 0.5 (2)[a]	
methyl isobutyl ketone		9.4 (1)[a]	
morpholine		13.7 (1)[a]	
n-butanol		12.2 (1)[a]	
n-butyl acetate		9.8 (1)[a]	
17-decane			
n-dodecane			
n-heptane	3.2 (1)[a]	9.9 ± 0.0 (2)[a]	6.7 ± 0.3 (3)[a]
n-hexane		11.0 ± 0.1 (2)[a]	
n-octane			
n-pentane			
n-propanol		10.6 (1)[a]	
n-undecane	3.8 (1)		
natural gas		12.4 (1)[a]	
nitromethane			
propane		12.6 (1)[a]	
pyrrolidine		10.1 (1)[a]	
tetrahydrofuran		12.0 (1)[a]	
toluene		7.4 ± 0.7 (2)[a]	
transformer oil			
xylene		x.7 (1)[a]	

[a] Nonstandard cup hurncr.

TABLE 2. "BEST VALUES" OF CUP-BURNER CONCENTRATIONS, VOL.%. (cont.).

Fuel	HFC-125	HFC-227ea	HFC-23
70% isopropanol in water			
80% methanol/20% *n*-heptane		8.3 (1)[a]	
acetone		6.5 (1)	
acetonitrile			
aviation gas, 100 octane, low lead			
benzene		4.8 (1)	10.6 (1)
carbon disulfide			
cyclohexane			
diesel			
diesel no. 2			
diethyl ether			
ethanol		8.0 ± 0.3 (3)	16 ± 0.0 (2)
ethyl acetate			
ethylene glycol			
Exxon Turbo Oil			
gasoline (unleaded)			
heptane (commercial)		6.7 (1)	12.6± 05 (2)
hydraulic oil (Mobil Fluid 350)			
hydrogen			
isobutanol			
isooctane			11.3 (1)
isopropanol			
Jet A/JP-5			
JP-4			
kerosene		6.4 (1)	12.5 (1)
methane			
methanol		9.7 ± 0.4 (2)	19 (1)
methyl isobutyl ketone			
morpholine			
n-butanol			
n-butyl acetate			
n-decane			
n-dodecane			
ri-heptane	8.9 ± 0.3 (2)[a]	6.6 ± 0.0 (4)	13.0± 0.2 (3)
ti-hexane			
ti-octane			
n-pentane			
n-propanol			
ii-undecane			
natural gas			
nitromethane			
propane			
pyrrolidine			
tetrahydrofuran			
toluene		4.8 ± 0.3 (3)	9.7 ± 0.0 (2)
transformer oil		6.6 (1)	12.8 (1)
xylene			

[a] Nonstandard cup burner.

TABLE 2. "BEST VALUES" OF CUP-BURNER CONCENTRATIONS, VOL.%. (cont.)

Fuel	HFC-236fa	IG-01	IG-100
70% isopropanol in water			
80% methanol/20% *n*-heptane			
acetone		38 (1)	29 (1)
acetonitrile		33 (1)[a]	
aviation gas, 100 octane, low lead		32 (1)[a]	
benzene			31 (1)
carbon disulfide			
cyclohexane		36 (1)[a]	
diesel			
diesel no. 2		27 (1)[a]	
diethyl ether		45 (1)	34 (1)
ethanol		41 (1)	35 ± 2.7 (3)
ethyl acetate		35 (1)[a]	
ethylene glycol		31 (1)[a]	
Exxon Turbo Oil			
gasoline (unleaded)		37 (1)[a]	
heptane (commercial)			
hydraulic oil (Mobil Fluid 350)		26 (1)[a]	
hydrogen			
isobutanol			
isooctane			
isopropanol		35 (1)[a]	
Jet A/JP-5		32 (1)[a]	
JP-4		32 (1)[a]	
kerosene			30 (1)
methane		35 (1)[a]	
methanol	8.0 (1)[a]	52 (1)	41 ± 3.5 (2)
methyl isobutyl ketone			
morpholine		38 (1)[a]	
n-butanol		36 (1)[a]	
n-butyl acetate			
ii-decane			34 (1)
n-dodecane			33 (1)
n-heptane	6.3 ± 0.4 (3)[a]	42 ± 1.4 (3)	33 ± 1.6 (3)
n-hexane		40 (1)	31 (1)
n-octane			34 (1)
ii-pentane			30 (1)[a]
ii-propanol			
n-undecane			33 (1)
natural gas			
nitromethane		34 (1)[a]	
propane		40 (1)[a]	
pyrrolidine			
tetrahydrufuran			
toluene		33 (1)	25 ± 2.0 (3)
transformer oil			27 (1)
xylene		26 (1)[a]	

[a] Nonstandard cup burner.

TABLE 2. "BEST VALUES" OF CUP-BURNER CONCENTRATIONS, VOL.%. (concl).

Fuel	IC-54I	IC-55	IG-100
70% isopropanol in water		26 (1)	
80% methanol/20% ti-heptane			
acetone	30 ± 0.6 (2)	31 (1)	
acetonitrile		16 (1)	
aviation gas, 100 octane, low lead	30 (1)	26 (1)	
benzene			
carbon disulfide		49 (1)	
cyclohexane		32 (1)	
diesel			
diesel **no.** 2		26 (1)	
diethyl ether	36 (1)		
ethanol	33 (1)	30 (1)	
ethyl acetate		30 (1)	
ethylene glycol		30 (1)	
Exxon Turbo Oil		16 (1)	
gasoline (unleaded)		26 (1)	
heptane (commercial)	32 (1)		
hydraulic oil (Mobil Fluid 350)		21 (1)	
hydrogen			
isobutanol		29 (1)	
isooctane			
isopropanol	28 (1)	28 (1)	
Jet A/JP-5		26 (1)	
JP-4			
kerosene	31 (1)		
methane		25 (1)	
methanol	41 (1)	39 (1)	
methyl isnbutyl ketone			
morpholine			
ti-butanol		33 (1)	
n-butyl acetate		26 (1)	
n-decane			
n-dodecane			
n-heptane	33 ± **3.0** (4)	*35* ± **3.7** (2)	
n-hexane	3I ± 0.4 (2)	29 (1)	
n-octane			
ri-pentane			
ti-propanol			
n-undecane			
natural gas			
nitromethane		32 (1)	
propane		34 (1)	
pyrrolidine		31 (1)	
tetrahydrofuran		32 (1)	
toluene	25 ± 0.5 (2)	26 (1)	
transformer nil	28 (1)		
xylene		24 (1)	

[a] Nonstandard cup burner.

TABLE 3. COMPARISON OF CUP-BURNER VALUES FOR OLD AND NEW PROCEDURE (*n*-HEPTANE).

	Extinguishment Concentration, vol.%	
Agent	Air Flow Fixed Arbitrarily	Plateau Determined
FC-218	6.1 (1) [24.4]	6.5 (1) [50.1]
FC-3-1-10	5.3 ± 0.0 (2) [51.4, 51.4]	5.5 (1) [50.1]

Table 4 presents an overview of the standard deviations observed for the 30 values for which thcrc is more than one source and do not include data detcrinined using the platcau method described above. Note that these are percentages of vol.% concentrations (i.e.. cach is a percent of a percent). The scatter **is** remarkably small. The average standard deviation for the halocarbon data is only 3%. That for the inert gases is, however, above 5%.

TABLE 4. STANDARD DEVIATIONS AMONG MULTIPLE SOURCES.

		Standard Deviation as %	
	Number	High	Average
Halocarbons	20	9.0	3.0
Inert Gases	10	10.7	5.7

Table 5 summarizes extinguishment concentrations for heptanc. the fuel most often employed for agent comparisons. Most determinations have been made with n-heptane; however, a fcw have also been made with commercial heptane. a mixture of isomers. The limited data fail to show a significant difference bctween the two fuels. Table 5 indicates that the heptane extinguishment concentration for Halon 1301 is higher than the value of 3.0 vol.% usually given for this agent/fuel combination.

TABLE 5. HEPTANE CUP-BURNER EXTINGUISHMENT CONCENTRATIONS.

Agent	*n*-Heptane	Commercial
Halon 1301	3.4 ± 0.0 (2)	3.2 (1)
FC-218	6.1 (1)[a]; [6.5 (1)]	
FC-3-1-10	5.3 ± 0.0 (2); [5.5 (1)]	
PIC-1311	3.2 (1)[a]	
HCFC Blend A	9.9 ± 0.0 (2)[a]	
HCFC-124	6.7 ± 0.3 (3)[a]	
HFC-125	8.9 ± 0.3 (2)[a]	
HFC-227ea	6.6 ± 0.0 (4)	6.7 (1)
HFC-23	13.0 ± 0.2 (3)	12.6 ± 05 (2)
HFC-236fa	6.3 ± 0.4 (3)[a]	
IG-01	42 ± 1.4 (3)	
IG-100	33 ± 1.6 (3)	
IG-541	33 ± 3.0 (4)	32 (1)
IG-55	35 ± 1.7 (2)	

[a] Nonstandard cup burner.

CONCLUSIONS

The analysis of the data collected shows very good agreement between various sources, though the number of comparisons that can be made is small. The values for Halon 1301 with heptane fuel appear to be slightly larger (around 3.2 to 3.4 vol.%) than the value of 3.0 usually assigned to this agent/fuel combination. There is some very weak indication that the use of the plateau method may give slightly large extinguishment concentrations, and a decision may have to be made eventually on whether to combine these data with others. The Task Group is expecting additional data submissions. To date, no data submitted have met the proposed ISO or NFPA standard requirements for both apparatus and method.

A database allowing storage, statistical analysis, summarization, and printout of the data collected has been developed and is available for distribution.

DISCLAIMER

Members of the NFPA 2001 Cup Burner Data Task Group are William Grosshandler, National Institute of Standards and Technology; Howard *S.* Hammel, DuPont Chemicals; Steve W. Hansen, Ansul Fire Protection; Lorne MacGregor, North American Fire Guardian Technology, Inc.; Paul E. Rivers, 3M Chemicals: Mark **L.** Robin, Great Lakes Chemical Corporation; Joseph A. Senecal, Kidde-Fenwal, Inc., Ronald *S.* Sheinson, Naval Research Laboratory, and Robert E. Tapscott (Chair), University of New Mexico. Although all of the members cited contributed to the assessment of data reported in this paper, this paper was prepared by R. E. Tapscott and does not necessarily reflect the views or conclusions of the Task Group or of any individual member.

This paper does not present official positions of the National Fire Protection Association and does not reflect NFPA policy. The NFPA is not responsible for the content of this paper.

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