DEVELOPMENT OF A STANDARD CUP-BURNER APPARATUS: NFPA AND ISO STANDARD METHODS

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ABSTRACT

The cup-burner apparatus, originally developed by Hirst and Booth in the late 1970s, has been widely employed in laboratory-scale fire suppression testing of the recently developed clean extinguishing agents. The wide variation in extinguishing concentrations obtained via the cup burner method, due to variations in apparatus design and/or operation, has resulted in a call for standardization of the cup burner method by the ISO 14.520 Committee on Gaseous Fire Extinguishing Systems and by the NFPA 2001 Technical Committee.

Described herein are the development and current status of the NFPA 2001 and ISO 14520 cup-burner standards. Apparatus design and operation is detailed. and results presented for a selection of fire suppression agents. Fundamental differences in the performance of halocarbon and inert gas agents were observed during the course of this work. The extinguishing concentration of halocarbon agents was found to be independent of the airflow past the cup, and the cup-bumer flame is more difficult to extinguish than full-scale fires. In the case of the inert gas agents. however, it was found that the extinguishing concentration increases as the airflow past the cup increases, and tests indicate that in the case of the inert gas agents the cup-burner flame is not as challenging as full-scale fires. These differences in performance stem from the fundamental differences between the halocarbon and the inert gas agents.

INTRODUCTION

In 1977, Hirst and Booth published their paper describing the development of the cup-bumer method, a laboratory-scale method for the determination of flame extinguishing concentrations of fire suppression agents [I].

A schematic diagram of the Hirst and Booth cup-bumer apparatus in shown in Figure I. The inner cup is filled with a liquid fuel. the level of which is adjusted by means of a leveling device. In the case of a gaseous agent, Hirst and Booth packed the cup with refractory materials. A mixture of air and suppression agent flows through a bed of glass beads and past the cup. A trial is begun by adjusting the fuel level in the cup and igniting the fuel. With the air flow held constant at a predetermined value and the liquid fuel level adjusted to lie at the top of the cup, the agent concentration in the air stream is gradually increased until the flame is extinguished. The extinguishing concentration is then calculated, either from the air and agent flow rates, or preferably by sampling of the air/agent stream at the lip of the cup followed by quantitative analysis, e.g., via gas chromatography.

The great value of the cup-bumer method was that for agents such as Halon 1301 and Halon 1211 the cup-burner flame proved to be more difficult *to* extinguish than full-scale fires of the same fuel, regardless of whether the full-scale fires were pool, spray, running, cluttered, or obscured. As pointed out by Hirst and Booth, this built-in safety factor makes the cup-bumer method ideally suited for use in determining design concentrations. As a result, in the NFPA Standards for both Halon 1301 and Halon 1211 the cup-burner extinguishing concentration served as the basis for determining design concentrations.

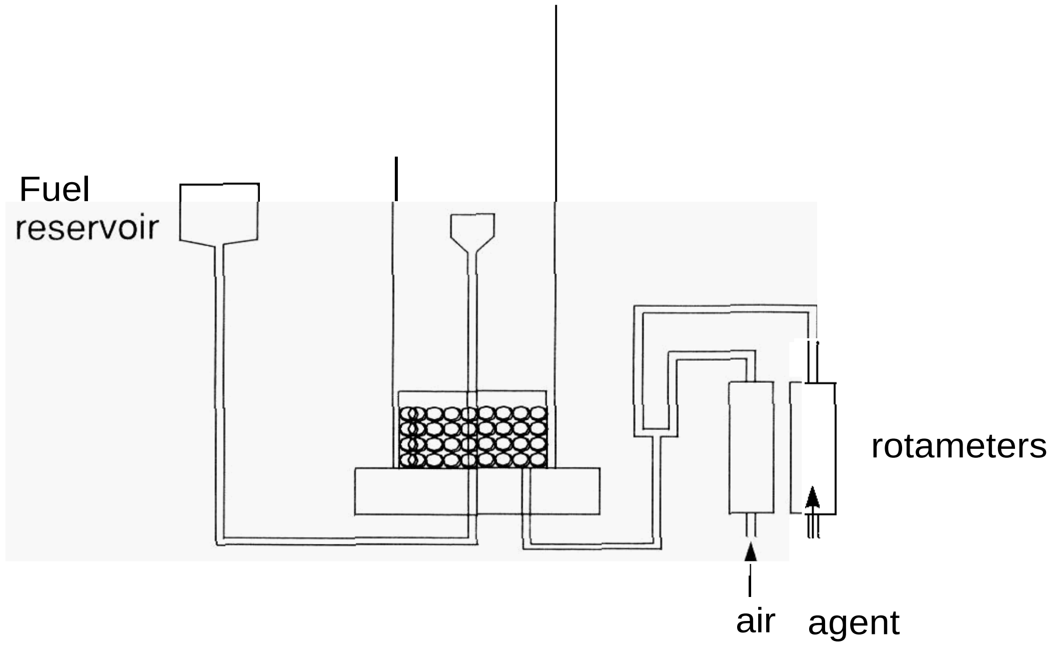

Figure 1. Hirst and Booth cup-burner apparatus.

Hirst and Booth attributed the greater stability of the cup-burner flame to three causes:

1. An adequate supply of fresh air is always available to the flame.
2. The flame is undisturbed by movements of the fuel surface or irregularities in the air flow past the cup.
3. The flame is anchored at its base by a premixed region, formed by the small eddy that results from the flow of air past the edge of the burner.

In recent years, numerous researchers have once again sought to employ the cup-burner apparatus for the determination of the fire extinguishing concentrations of halon alternatives. However, many of these new agents were initially available only in small quantities. and as a result researchers constructed scaled-down versions of the original Hirst and Booth apparatus that require much **less** agent. Unfortunately, in many cases, this was done without a clear understanding of the effects of scale on the measured extinguishing concentrations.

Creitz *[2]* in 1961 pointed out that the extinguishing concentration determined in a concentric tube burner was dependent upon the rate of fuel supply and the flow rate of air past the inner tube. Hirst and Booth [1] pointed out that (1) the airflow past the edge of the cup forms an eddy, which results in direct mixing of fuel vapor and air, and *(2)* that the tlame stability is strongly dependent upon this effect. In the cup-burner apparatus. the flame is anchored at its base by ***a*** partially premixed region formed by the small eddy that results from the flow of air past the edge of the burner. The relative velocity of the fucl vapor leaving the surface and the air flowing past the burner affects the composition of the premixed region, and hence the stability of the flame. As **a** result, Hirst and Booth took measures to eliminate any flow disturbances, specifying, for example, the use of ***a*** cup with a slowly increasing diameter and the minimum height of the cup above the glass beads.

In addition to the requirement of maintaining an undisturbed air flow past the cup, researchers have established that numerous additional factors affect the extinguishing value obtained from the cup-burner apparatus, including the following:

Chimney diameter, D	Linear velocity of air
Cup diameter, d	Linear velocity of gaseous fuel
Chimney to cup diameter ratio D/d	Temperature of air, agent
Chimney length	Preburn time
Cup height above beads	Rate of agent increase in air stream
Distance of fuel below top of cup	Oxygen content of air supply

The effect of scale on extinguishing concentrations measured in the cup-burner apparatus has been reported by several investigators [3,4].

DEVELOPMENT OF A STANDARD CUP-BURNER METHOD

Current national and international tire standards continue to employ the extinguishing concentrations obtained with the cup burner as the basis for the development of minimum design concentrations for hazards containing Class B liquid or gaseous tlammables. As a result, it has been recognized that a standard method affording laboratory-to-laboratory reproducibility is required. As a result, in January 1997 the ISO 14520 Committee appointed a task group charged with developing a standard apparatus and procedure. In June of the same year, the NFPA 2001 Technical Committee also appointed a task group to develop a standard apparatus and procedure.

Both task groups concluded that a single, well-defined apparatus, and a detailed method for its operation were required. The 85 mm chimney size of the original Hirst and Booth apparatus was chosen, based upon the observation that in the hands of Hirst and Booth this design and scale of apparatus produced a stable flame, one that was more difficult to extinguish than full-scale fires of the same fuel. A schematic diagram of the ISO/NFPA standard cup-burner apparatus is shown in Figure 2.

The details of the operation of the apparatus were based upon the experience of the task group members with the cup burner and also upon the original observations of Hirst and Booth. For example, because the extinguishing concentration is dependent upon the airflow past the cup, the new standards call for the experimental determination of this dependence. This contrasts with the common practice in recent years of setting the airflow to an arbitrary value of 40 L/min and assuming that this airflow lies within the airflow region in which the extinguishing concentration is independent of the airflow (the so-called "plateau" in the extinguishing concentration vs. airflow plot).

Minor differences currently exist between the NFPA and ISO standard methods. Dimension tolerances are slightly different and the specification of the initial temperature of the fuel is slightly different; it is believed that these minor differences will have no affect on the results. The ISO standard also requires the measurement of the extinguishing concentration for the condition of the fuel heated to 5 °C below its boiling point: NFPA 2001 contains no such requirement.

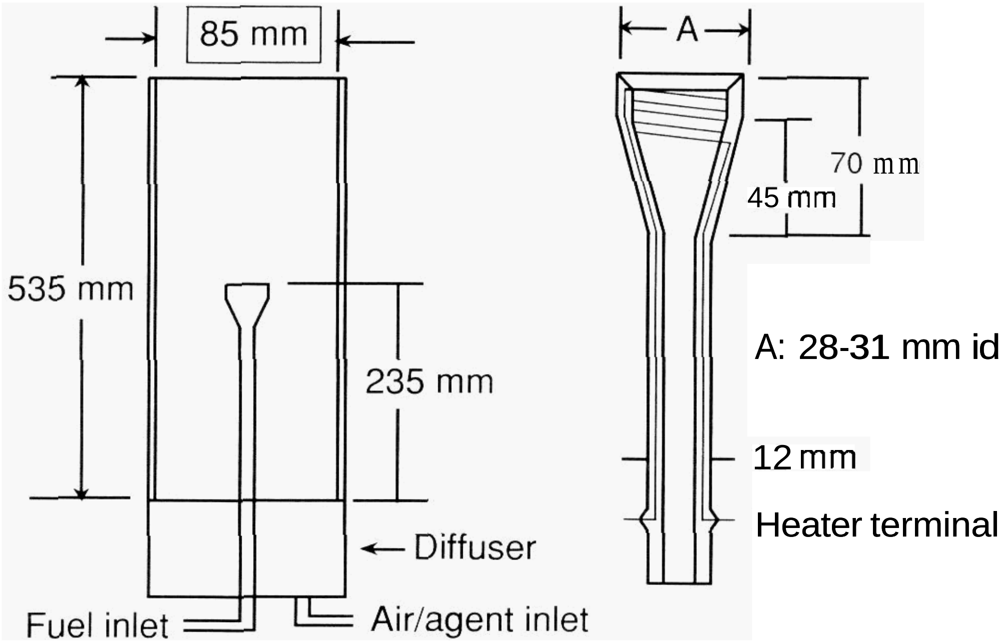

Figure 2. Standard cup-burner apparatus.

Erdem Ural of Fenwal Safety Systems has examined the current standards and has found that the recommended procedure for *gaseous* fuels, which was based upon the original procedure of Hirst and Booth, requires modification [5]. **A** proposed method has been developed by Dr. Ural and will be submitted to the cup-burner task groups of ISO 14520 and NFPA 2001.

DETERMINATION OF AGENT CONCENTRATION AT EXTINGUISHMENT

The measurcment of the suppression agent concentration at the point of extinguishment can be problematic when employing flow rates from rotameters or mass flow meters. At higher air flows. significant backpressure can develop at the entrance to the mixing chamber. To obtain the actual tlow rates, the effect of backpressure on the volumetric tlow rate must be accounted for: unfortunately no straightforward correction method exists. Therefore. a gas chromatographic method was developed, the results of which are independent of the backpressure developed within the cup-burner apparatus.

Immediately following flame extinction. a sample of the gas stream at a point ncar the lip of the cup was collecied through a length of plastic tubing attached to a Hamilton 1 L precision gas syringe. The sample was then injected into a 1 L Tedlar bag and subjected to gas chromatographic analysis. Gas chromatographic columns are available that will separate oxygen, nitrogen and carbon dioxide, and hence the technique is applicable to the inert gas agents as well as the halocarbon suppression agents.

EXTINGUISHING VALUES FOR HALOCARBONS: HFC-227EA

Extinguishing concentrations of FM-200'' (HFC-227ea) were determined for six liquid fuels employing the standard apparatus and procedures described in the current drafts of NFPA 2001 Standard on Clean Agent Fire Extinguishing Systems and ISO 14520 Gaseous Fire-Extinguishing Systems. The extinguishing values and statistical analysis of the data are summarized in Tables 1 through 6. With the exception of acetone, the ''plateau region" in the air flow vs. concentration plot lies between 10 and 50 L/min of air flow, **k.,** the extinguishing concentration is independent of the air flow over the region between 10 and 50 L/min. For acetone, the plateau begins at approximately 25 L/min air flow.

TABLE 1. HFC-227EA EXTINGUISHING CONCENTRATIONS FOR ETHYL ALCOHOL, DENATURED.

Air Flow (L/min)	Extinguishing Conc., % v/v	Average	Standard Deviation
13.9	8.4 8.4 8.3	8.4	0.04
20.6	8.6 8.5 8.5	8.5	0.06
27.3	8.3 8.6 8.5	8.4	0.14
34.2	8.4 8.7 8.5 8.4 8.6	8.5	0.13
41.1	8.4	8.4	0
51.8	8.5 8.6 8.5	8.5	0.07
18 points	Low	8.3	
	High	8.7	
	Overall Average	8.5	
	Overall Std. Dev.	0.11	

TABLE 2. HFC-227EA EXTINGUISHING CONCENTRATIONS FOR TOLUENE.

Air Flow (L/min)	Extinguishing Conc.. % v/v	Average	Standard Deviation
13.9	5.1 5.2 5.2	5.2	0.09
20.6	5.2 4.8	5.0	0.33
21.3	5.2 5.1 4.9	5.1	0.13
34.2	4.9 5.0 5.0 4.9 4.9 4.8	4.9	0.07
41.1	4.8	4.8	—
51.8	4.9 5.1 5.0	5.0	0.09
18 points	LOW	4.8	
	High	5.2	
	Overall Average	5.0	
	Overall Std. Dev.	0.15	

TABLE 3. HFC-227EA EXTINGUISHING CONCENTRATIONS FOR *n*-HEPTANE.

Air Flow (L/min)	Extinguishing Conc.. % v/v	Average	Standard Deviation
13.9	6.5	6.5	—
20.6	6.6	6.6	—
21.3	6.4	6.4	—
34.2	6.3 6.5 6.4 6.4 6.5	6.4	0.10
41.1	6.4	6.4	—
51.8	6.5 6.4 6.6 *6.5* 6.5	6.5	0.06
14 points	Low	6.3	
	High	6.6	
	Overall Average	6.5	
	Overall Std. Dev.	0.08	

TABLE 4. HFC-227EA EXTINGUISHING CONCENTRATIONS FOR ACETONE.

Air Flow (L/min)	Extinguishing Conc., % v/v	Average	Standard Deviation
13.9	6.5 6.5 6.4	6.5	0.06
20.6	6.7 6.5 6.6	6.6	0.09
27.3	6.7 6.8 6.8 6.7 6.8	6.8	0.06
34.2	6.8 6.9 6.8 6.9 6.1	6.8	0.09
41.1	6.8 6.8	6.8	0.09
51.8	6.8	6.8	—
I3 points	Low	6.5	
	High	6.9	
	Overall Average	6.8	
	Overall Std. Dcv.	0.07	

TABLE 5. HFC-227EA EXTINGUISHING CONCENTRATIONS FOR 2-PROPANOL.

Air Flow (L/min)	Extinguishing Conc.. % v/v	Average	Standard Deviation
13.9	7.2 7.0 7.1 7.1	1.1	0.07
20.6	7.0 7.1 7.2 7.2	7.1	0.08
21.3	7.1 7.4 7.1	7.2	0.20
34.2	1.4 7.2 7.2 7.3 7.3	7.3	0.09
41.1	7.2 1.2 1.3	7.2	0.07
51.8	7.2 1.2	1.2	0.00
21 points	Low	7.0	
	High	7.4	
	Overall Average	7.2	
	Overall Std. Dcv.	0.12	

TABLE 6. EXTINGUISHING CONCENTRATIONS FOR METHYL ALCOHOL.

Air Flow (L/min)	Extinguishing Conc., % v/v	Average	Standard Deviation
13.9	10.2 10.2 10.1 10.2	10.2	0.05
20.6	10.4 9.9 9.8 10.3	10.1	0.29
21.3	10.5 10.3 10.3 10.1 10.2	10.3	0.14
34.2	9.9 10.1 10.3 10.1 10.0	10.1	0.14
51.8	9.8 10.5 10.4	10.2	0.36
21 points	Low	9.8	
	High	10.5	
	Overall Average	10.2	
	Overall Std. Dev.	0.20	

EXTINGUISHING VALUES FOR INERT GASES: INERGEN, NITROGEN

In contrast to the behavior of the halocarbon agent HFC-227ea, the extinguishing concentrations for the inert gas agents lnergen and nitrogen show a strong dependence upon the airflow past the cup; extinguishing concentrations increase as the airflow increases (Figures 3 and 4).

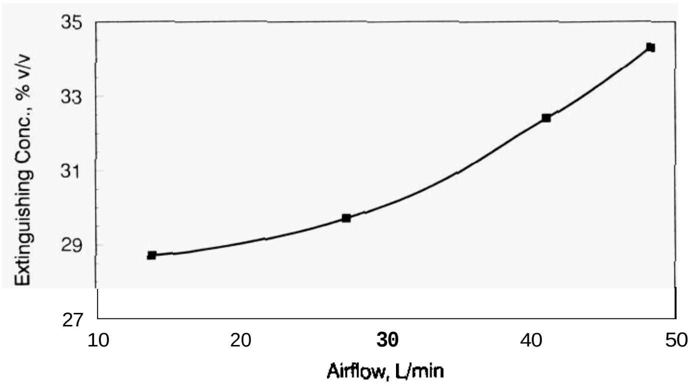

Figure 3. Extinguishing concentration of inergen for n-heptane fuel.

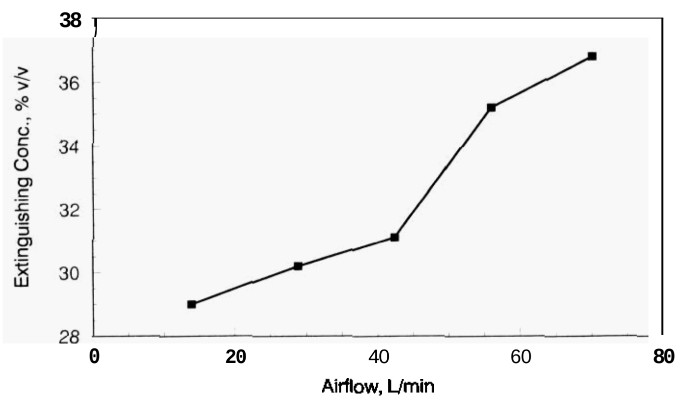

Figure 4. Extinguishing concentration of nitrogen for n-heptane fuel.

SCALE EFFECTS

The VdS Schadenverhutung has recently investigated the effect of scale on the performance of clean fire supprcssion agents [6]. In addition to the standard cup-burner apparatus, the VdS has examined the performance of the agents in a scaled-up cup burner and at room-scale in a 150 m^3 cnclosure. The "largc" cup burner is a scale-up of the standard burncr by a factor of 4.7, e.g., the chimney of the large cup-burner apparatus is 4.7 x 85 = 400 mm in diameter.

In the case of the inert gas agents Inergen and nitrogcn, a scale effect was observed, i.e., the extinguishing concentration increased as the scale of the cup burner increased (Figure 5). In addition. extinguishment of the full-scale fire required more agcnt than did extinguishment of the flame in the standard cup burner. In the case of nitrogen. extinguishment of the full-scale fire required 18% more agent than did cxtinguishmcnt of the cup-burner flame. For Inergen, an additional 12% of agent was required for extinguishment of the full-scale fire.

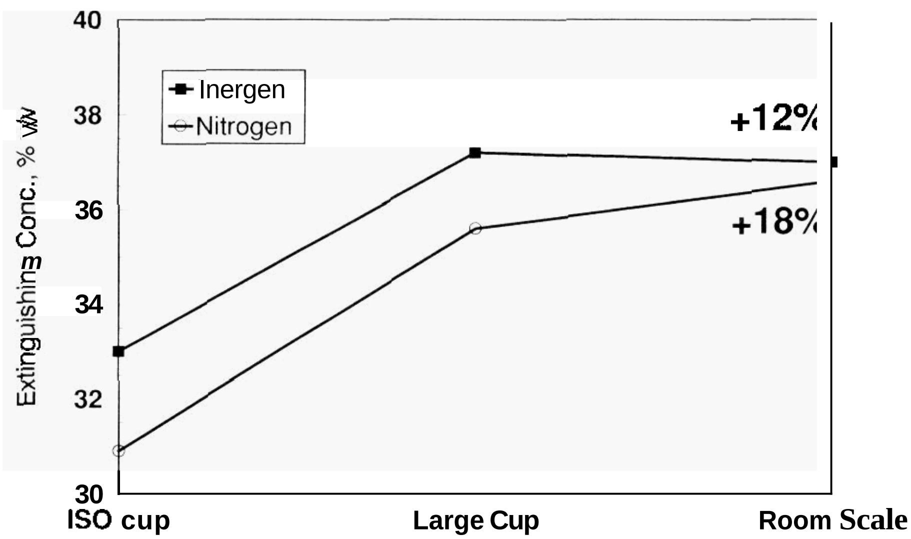

Figure 5. Extinguishment with inert gas agcnts

No scale effect was observed in the case of the halocarbon agent HFC-227ea, as seen in Table 7. Hence, in contrast to the case of the halocarbon agent HFC-227ea, the standard cup-burner flame is *not* the worst-case fire for the inert gas agents Inergen and nitrogen.

TABLE 7. SCALE EFFECT ON EXTINGUISHING CONCENTRATION: *n*-HEPTANE FUEL.

Agent	ISO Cup Burncr Ext. Conc.. % v/v	VdS Large Cup Burner Ext. Conc.. % v/v	Full-Scale Fire Ext. Conc., % v/v
Inergen	33.0	37.2	37.0
Nitrogen	30.9	35.6	36.6
HFC-227ea	6.6	6.7	6.7

CONCLUSIONS

A standard cup-burner apparatus and a procedure for its operation have been developed by the cup-burner task groups of ISO 14520 and NFPA 2001. The standard provides excellent laboratory-to-laboratory reproducibility of extinguishing concentrations for the case of liquid fuels. As originally noted by Hirst and Booth in their examination of the performance of Halons 1301 and 1211, the extinguishing concentration for the halocarbon agent HFC-227ea is independent of the airflow over a large range of airflows. In addition, the cup-burner flame is more difficult to extinguish than full-scale fires of the same fuel. Hence, the cup burner is ideally suited for the establishment of design concentrations for halocarbon fire suppressant agents.

In the case of the inert gas agents Inergen and nitrogen, however, the extinguishing concentration is strongly dependent upon the airflow past the cup; the extinguishing concentration steadily increases as the airflow increases. In addition, it has been observed that for these inert gas agents the cup-burner flame is *not* the most challenging fire: a scale effect has been observed wherein more agent is required for the extinguishment of full-scale fires than is required for the extinguishment of the cup-burner flame.

The observed differences in the performance of halocarbon and inert gas agents are linked to the fundamental differences between the two agent types. Inert gas agents afford extinguishment solely through the physical mechanism of oxygen dilution, whereas halocarbon agents extinguish tires through both physical and chemical mechanisms.

The observed behavior of the inert gas agents suggests that the standard cup burner is perhaps not appropriate for the establishment of design concentrations for inert gases. The VdS, for example, has suggested that the large-scale cup burner may be appropriate, since the extinguishing concentrations obtained in this apparatus more closely match the required full-scale extinguishing concentrations.

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