A COMPARISON OF THE NMERI AND ICI-STYLE CUP BURNERS

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INTRODUCTION

The cup-burner apparatus is a tool, like that used in any professional or technical trade. This tool contains a small fuel cup inside a glass chimney, and is used to determine extinguishment concentrations for different compounds. A flame extends 2 to 3 inches above the cup. An air flow rate from 10 to 40 L/min is maintained through the apparatus and flame suppressing agents are mixed into the air stream increasing increments until the flame is extinguished. The agent concentration in the air when the flame goes out is the extinguishment concentration. This value is one basis for establishing design concentrations by the International Standards Organization (ISO), National Fire Protection Association (NFPA),[1] International Maritime Organization (IMO), and a variety of other organizations. The apparatus is used to determine the extinguishment concentrations for "in-kind halon replacements. The cup-burner is used define a starting point for large-scale tests.

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 halons (tire extinguishing agents). Halons are believed to contribute stratospheric ozone depletion. Halon production (for all but "essential" uses) ended at the beginning of 1994, 10 years ahead of the targeted date of 2004 in the orginal Montreal Protocol.

As part of a research effort on halon replacements, NMERI/CGET has developed the NMERI Standard Cup-Burner[2,3] and has performed numerous extinguishment concentration measurements. Many experimental variables are associated with the measuring extinguishment concentrations --- test apparatus configuration, size, shape, operator, test objective, etc.

It is has become well recognized that the cup-burner extinguishment concentration should not be regarded as indicative of real-world requirements for suppressing a particular fuel under all circumstances. As stated by Robin, "the value should be employed as a starting point for further investigation into real-world requirements for a particular fuel."'

THE DEBATE

There is now a debate concerning two cup burner experimental techniques. The original apparatus and methodology were developed by Hirst and Booth at Imperial Chemical Industries (ICI) in 1970 and refined in 1973.[4] The second apparatus was developed by CGET/NMERI in 1987'.

During the early **1960s** Halon 1301 and 1211 were being introduced to the fire protection community and were going through the approval process, much the same as today's halon replacements. The ICI-style apparatus was designed to provide extinguishing concentrations similar to those determined from large-scale tests on a limited number of fuels. Early Halon 1301 cup-burner concentrations ranged from 3 to 4.5 vol.%. Hence, a Halon 1301 design concentration of ***5.0*** vol.% was determined to be acceptable by the NFPA.[6] The 5.0 vol.% concentration provides a Safety Factor of 1.7 above the cup burner value. The ICI-style burner could be run with confidence for other fuels and provided designers with a to predict design concentrations.

The NMERI Standard cup burner is a greatly improved version of the ICI-style cup burner. Designed to obtain extinguishment concentration values for a wide variety of unique compounds different than the halons being phased out, it has become NMERI's research tool and is used to compare a wide variety of extinguishing agents (and fuels).

THE CUP BURNER EXPERIMENT

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-bumer value.

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-bumer results was performed. The study included 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 the errors in the measurement of air and agent flow rates and times are the most critical in determining the precision of the extinguishment concentration. The higher the flow rates the more difficult they are to measure accurately. Large flow meters are simply not as accurate as small ones.

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% confidence limits of 10.1% (gases) and 17.9% (liquids) of the extinguishment concentration reported. These values correspond to standard deviations of 5.0% and 8.8%, respectively. The cumulative errors associated with accurately measuring the air and agent flow rates outweighs the dependence of extinguishing concentration on chimney/cup configuration differences. Therefore, the differences in reported values is primarily due to flow measurement differences, not differences in apparatuses (size, shape, etc.). It is unlikely that the use of a single apparatus by various laboratories will yield cup burner values with less scatter than is currently reported, unless flow measurement devices and techniques are also standardized.

TABLE I - EVALUATION OF MEASUREMENT ERRORS IN CUP BURNER EXPERIMENTS.

Measurement	Number of Samples	Mean Value, L/min	95 Percent Confidence Limit (2a), 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	fll (2.2%)
Agent Flow (liquid)			
High Rate	10	3.73	±0.22 (5.9%)
Low Rate	10	2.44	±0.18 (7.4%)

DEVELOPING A STANDARD CUP BURNER

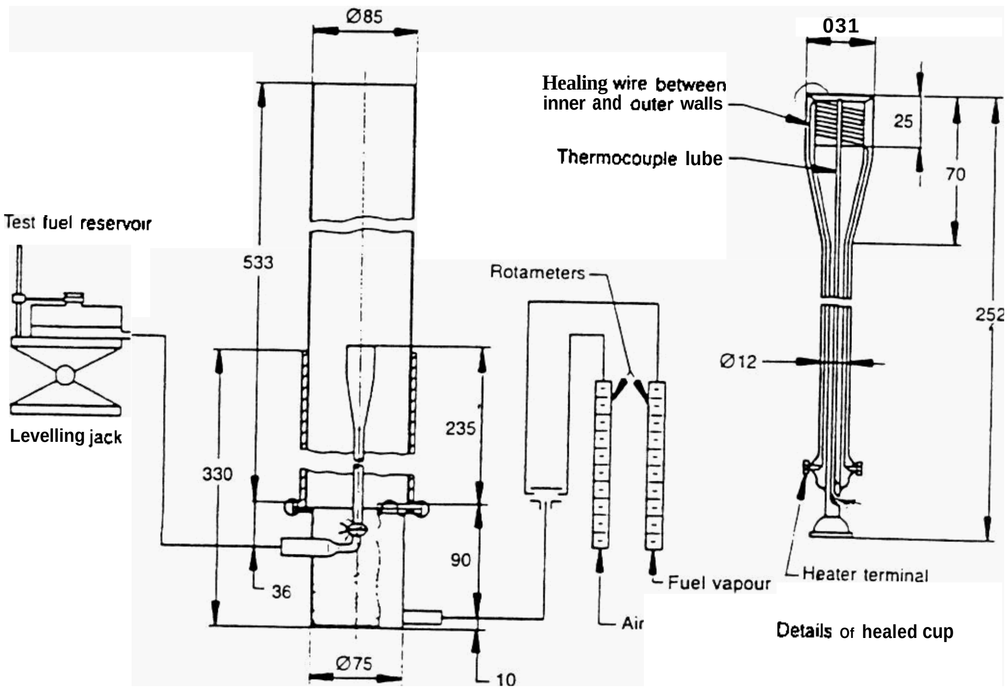
The International Standards Organization Technical Committee 21 Subcommittee 8 (ISO/TC21/SC8) Gaseous Media Fire Extinguishing Systems committee is in the process of developing (standardizing) a single cup burner apparatus with fixed dimensions. The NMERI Standard cup burner is outside the range of these dimensions. Detailed operational procedures have been written and will likely be adopted at the next committee meeting (May 1997). Flow measurement details are not addressed in the draft ISO Standard. There is a strong contingent on the ISO committee that would like to see a standard "single" apparatus adopted. The feeling is that there must be only one "standard apparatus." The ICI-style has been selected (Figure 1), even though the majority of the cup burner values in the present ISO and NFPA standards were derived from the NMERI apparatus. It is important to note that the NMERI determined values are equivalent, "within the error of the experiment," to those derived with the ICI-style apparatus.

DRAWBACKS OF THE ICI-STYLE CUP BURNER

The drawbacks of the ICI-style cup apparatus are (1) Data scatter larger than from that obtained with the NMERI design. *(2)* Significantly more material required than with the NMERI design (Figure *2*). This is important when working with expensive compounds or research compounds available in only small amounts. (3) Inability to handle both gaseous and "liquid" agents. By "liquid" agents, we mean, agents that have boiling points near or above room temperature but have sufficiently high vapor pressures such that the vapor can reach an extinguishing concentration. (4) Agent discharge rates monitored by volumetric flow meters rather than by weight **loss.** The latter method requires no gas flow calibration. ***(5)*** A shorter plateau region than can be obtained with the NMERI design. The "plateau" region is a region where results do not vary greatly with air flow rate (Figure 3).

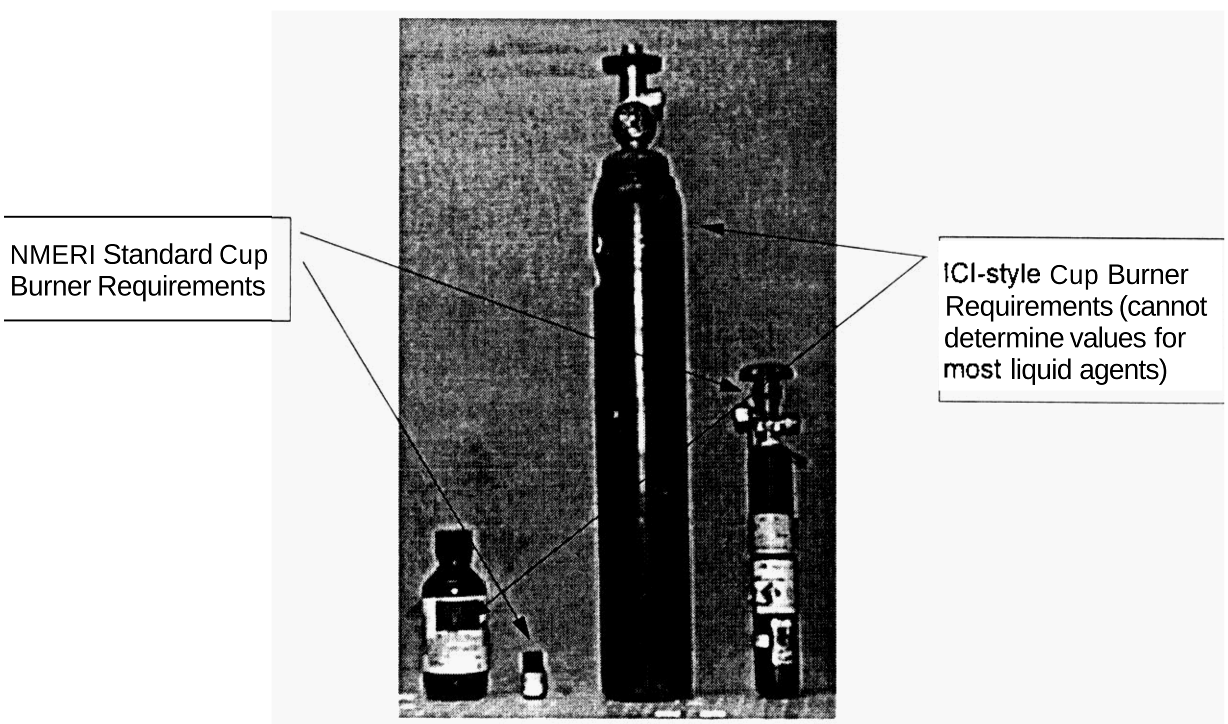
DIFFERENCES BETWEEN THE NMERI STANDARD AND ICI-STYLE BURNERS

The major differences between the NMERI and ICI-style burners are the (1) chimney diameters and flow rates through the chimney, (2) protruding flame cup arm in the NMERI chimney, (3) quantity of agent required for a test, *(4)* unique NMERI air / agent mixing chamber, and ***(5)*** ability to test liquid and



DIMENSIONS IN MILLIMETRES

Figure 1. ICI-style cup-burner setup likely to be adopted as the ISO standard apparatus.



Liquid Agents Gaseous Agents

Figure 2. Typical container sizes (agent volumes) required to determine cup-burner extinguishment concentrations with the ICI-style and the **NMERI** standard cup burners. The large agent volumes required for the ICI-style are unacceptable when only research quantities are available for testing.

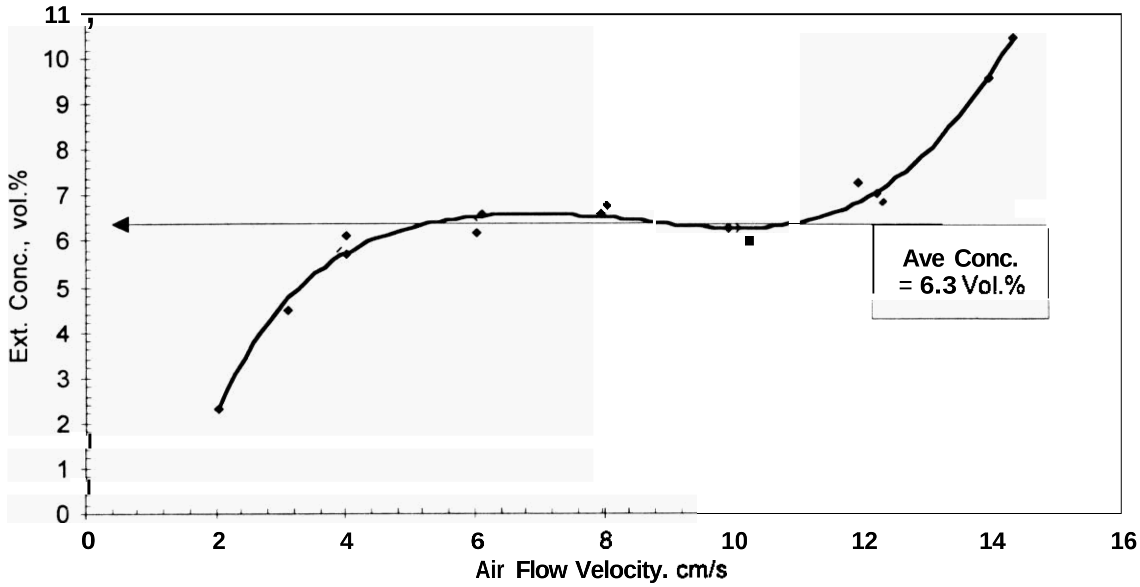


Figure 3. Ext. conc. versus air linear velocity through the NMERI Standard Cup Burner for FM-200.

and near-room temperature boiling point compounds with the NMERI apparatus, due to the high air flow rates and mixing chamber design.

At NMERI, different cup-burner test configurations and procedures *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 electronic bubble flow meters (Figure 4). Agents with boiling points near and significantly above room temperature ("liquid agents) are metered with a discharge cylinder, needle valve, and an electronic scale having computer data acquisition (Figure 5).

EXTINGUISHMENT CONCENTRATION VS FLOW RATE EFFECTS

The data in Table 2 shows the chimney effect vs cup diameter in a small burner presented by Robin' with Great Lakes Chemical Corp. for FM-200 (HFC-227ea). Operating characteristics of the NMERI Standard have also been included for comparison. There are several problems with Robin's data (if the intent was to compare with the **NMERI** apparatus): (1) details of Robin's apparatus are not provided (the unique mixing chamber is critical to the NMERI experimental design), (2) the NMERI cup burner is operated at an air linear velocity of 5 to 10 cm/s (less than that presented by Robin), and **(3)** the NMERI cup diameter is 13 mm (which preserves the ICI-style cup-to-chimney ratio), again critical to the NMERI experimental design.

Figure **3** shows the extinguishment concentration **as** the linear velocity through the NMERI Standard Cup Burner is varied. There is a plateau region from 5 to 10 cm/s.

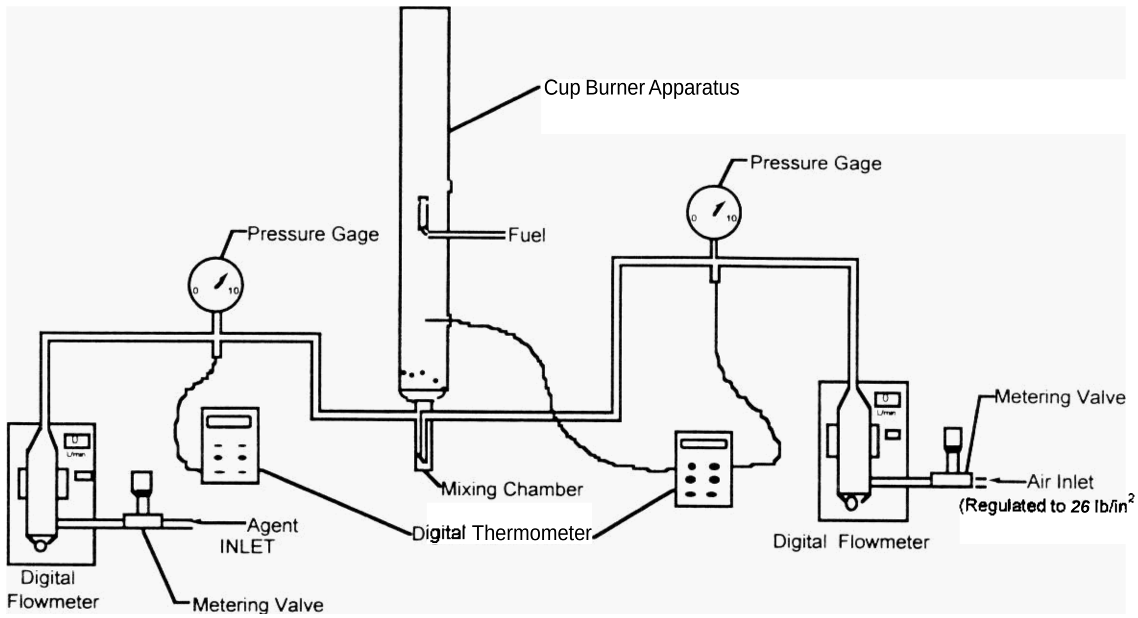


Figure 4. NMERI gaseous agent test setup using electronic bubble flow meters.

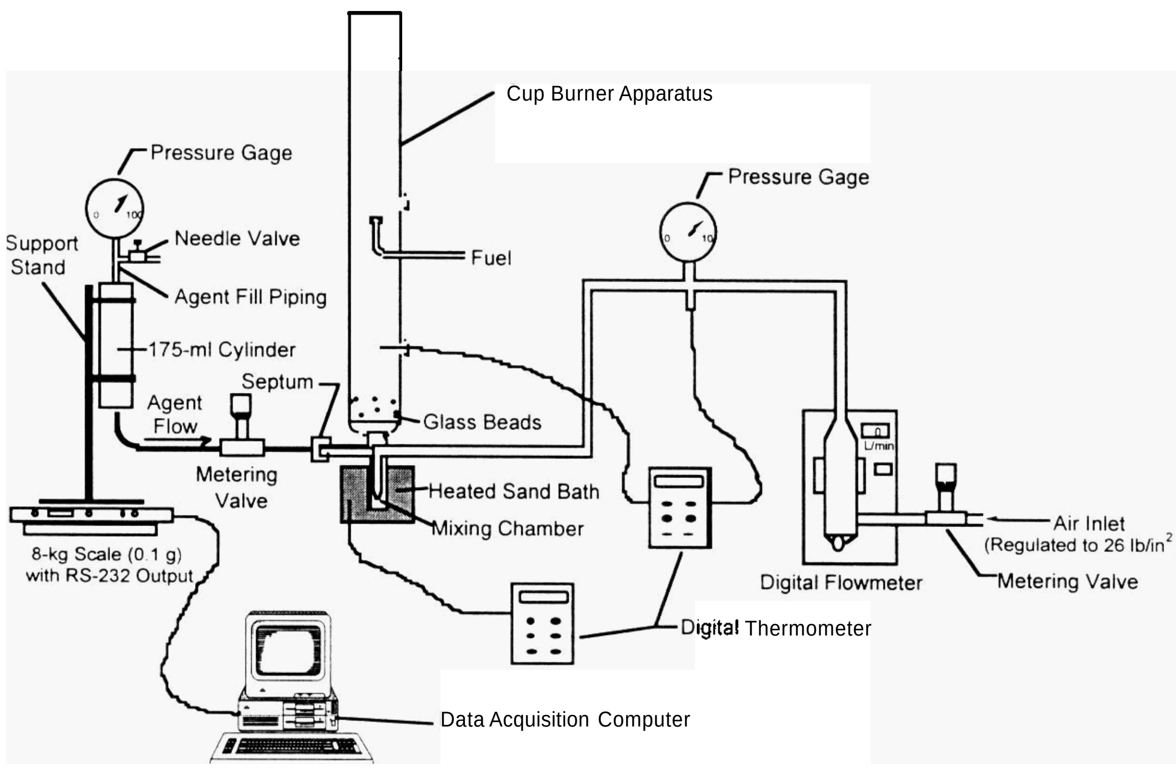


Figure 5. NMERI liquid agent test setup

TABLE 2. CUP DIAMETER EFFECT ON FM-200 EXTINGUISHING CONCENTRATION.

Chimney ID, mm	Cup ID, mm	Ext. Conc., Vol.%
Robin Data[a]		
51	15	6.0
51	20	6.3
51	28	6.4

[a] *n*-Heptane fuel, air linear velocity 13.3 cm/s, details of the apparatus design were not provided.

CUP-BURNER TEST RESULTS

Average extinguishment concentrations for various compounds determined with the NMERI and ICI-style cup burners are presented in Table 3 for heptane fuel. The organizations which have reported ICI-style cup burner values are the Naval Research Laboratory (NRL), Great Lakes Chemical Company, Fenwal Safety Systems, and 3M. These data were obtained from personal communications, NFPA 2001, and other publications. Analysis of the data in Table 3 indicates that, despite the differences in cup burner design and variations in test techniques, extinguishment values for compounds agree well between the NMERI Standard and ICI-style cup burners. The agreement is generally within ± 5 to 10%, which is approximately the same variability as predicted from the error analysis.

CONCLUSIONS

The cup-burner experiment is a classic laboratory model which has been developed to test and evaluate halon replacements. An international standard cup-burner is currently being developed. At present, the draft standard limits the determination of cup-burner extinguishment concentrations for a wide variety of future compounds, due to the limitations presented. The extinguishment concentrations of agents that have boiling points near room temperature or those which are blends of different compounds are difficult to measure. Such materials do not vaporize well within the ICI-style cup burner. The NMERI Standard apparatus overcomes these problems.

The values generated with the NMERI apparatus are equivalent to the values generated with ICI-style apparatuses., There is no technical reason why the NMERI Standard Cup Burner should not he considered equivalent or even preferred to the ICI-style cup burner. As stated earlier, the cup-burner value is only a starting point for larger-scale testing, and not a definitive value for all circumstances.

TABLE 3. COMPARISON OF n-HEPTANE CUP BURNER EXTINGUISHMENT CONCENTRATIONS -- NMERI STANDARD VERSUS ICI-STYLE CUP BURNERS.

Agent	[a]NMERI Std.	ICI-Style Cup-Burner Values							
		[a]NMERI	[a]NRL	'Great Lakes	[a]Fenwal	[a]3M	[a]NIST	'Mean	Ave Dev.. %
HFC-23	12.6	---	12	12.7	12.0	12.9	12.0	12.4 ± 0.4	3
HCFC-124	6.7	---	---	---	6.4	---	7.0	6.7 ± 0.3	5
HFC-125	9.4	---	8.8	9.3	8.1	---	8.7	8.7 50.4	5
FC-3-1-10	5.0	---	5.2	4.1	5.5	5.9	5.3	5.2 ± 0.6	11
FC-5-1-14	4.4	---	---	---	4.4	4.0	---	4.2 ± *0.2*	5
Halon 1211	3.2	---	3.6	3.3	3.8	---	---	3.6 ± 0.2	6
Halon 1301	2.9	---	3.1	3.5	3.0	3.9	3.2	3.4 ± 0.3	9
HFC-227ea	6.3	---	6.6	5.9	---	7.5	6.2	6.6 ± 0.5	8
HBFC-22B1	4.4	---	4.1	3.93	3.9	---	---	4.0 ± 0.1	2
N_2	30	---	30	---	---	---	32	3151	3
cO2	20.4	---	21	---	28	---	---	24.5 ± 3.5	14
INERGEN	30.9	30.4	—	---	---	---	---	(b29.1)	---
IG-55 (N_2/Ar)	32.2	32.3	---	---	---	---	---	32.3	---
IG-01 (Ar)	39.3	39.1	41	---	---	---	41	40.5 ± 0.8	2

"values are v lume % c icentrations (Reference 2).
Value repor d by agen manufaclurer (Ansul Corp) (Reference 2).

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