FIRE SUPPRESSION TESTING: EXTINGUISHMENT OF CLASS A FIRES WITH CLEAN AGENTS

Mark L. Robin
Hughes Associates, Inc

Thomas F. Rowland and Mark D. Cisneros
Great Lakes Chemical Corporation

ABSTRACT

The fire suppression characteristics of a selection of clean extinguishing agents were examined employing Underwriters Laboratories Standards UL **2166** (halocarbon agents) and UL 2127 (inert gas agents). Agents tested included HFC-227ea (FM-200®), HFC-23, HFC-125, NAF-S-III, Inergen (IG-541), and nitrogen. The most challenging fires in terms of the concentration of agent required for the halocarbon agents were the **PMMA** plastic sheet fires. In contrast, for the inert gas agents the most challenging fire was found to be the wood crib fire; at concentrations capable of readily extinguishing the plastic sheet fires, the inert gas agents were unable to provide sufficient cooling to prevent re-ignition of the wood crib following a 10-min soak period.

INTRODUCTION

Underwriters Laboratories has recently published new standard test methodologies for the evaluation of clean agent fire extinguishing systems, the successful completion of which will be required for the listing of clean extinguishing agent systems [1, 2]. The new standards covering halocarbon and inert gas systems are:

1. *UL 2166 Standard for Halocarbon Clean Agent Extinguishing System Units*
2. *UL 2127 Standard for Inert Gas Clean Agent Extinguishing System Units*

Agents tested in this program included HFC-227ea (FM-200®), HFC-23, HFC-125, NAF-S-III, Inergen (IC-541) and nitrogen.

EWEFUMENTAL PROCEDURE

TEST FACILITY

The test facility is shown schematically in Figure 1. The nominal internal dimensions of the test portion of the facility are 8 x 4 x 3.6 m (height); precise measurement of the test portion of the facility yielded a total volume of 115 m' (4061 ft^3). The enclosure walls are constructed of standard concrete cinder block, filled with insulation, and covered on the interior with 5/8 in. gypsum wallboard. Both the ceiling and floor are composed of two layers of 3/4 in. plywood on wooden 2 x 6 joists, with alternate layers of plywood staggered so that no joints overlap. The ceiling is also covered with 5/8 in. gypsum wallboard; the walls and ceiling have been finished with tape and joint compound and painted with two coats of primer (Kilz). The windows consist of standard units employing safety glass and are covered on the interior with Lexan sheets. The enclosure door is of standard solid core construction. **A** 1 **x** 1 m hinged positive pressure vent installed in a recess in the ceiling was weighted down with a 20-Ib cinder block for tests involving **HFC-227ea,** HFC-125, and NAF-S-III; it was left open during testing of HFC-23, Inergen, and nitrogen. The ventilation inlet to the enclosure, through an underfloor duct, remained closed during this program. Temperature control of the room is provided by a 3.5-ton commercial heat pump unit, the inlet and outlet of which are equipped with closable shutters. The exhaust system is also fitted with a closable shutter.

INSTRUMENTATION

Enclosure Pressure. Enclosure pressure was monitored with a Lucas-Schaevitz Model P3091 pressure transducer with a range of -4.9 to +4.9 kPa (-0.72 to +0.72 psig).
Nozzle Pressure. Nozzle pressure was monitored with an Omega Model PX-302 vented-gage pressure transducer with a range of 0 to 6.9 MPa (0-1000 psig).

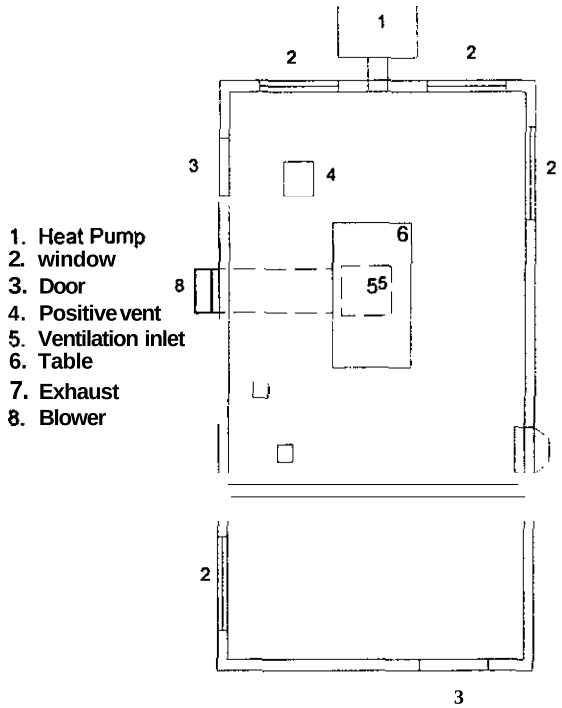

Figure 1. Test Facility.

Cylinder Pressure. Cylinder pressure was monitored with a Setra pressure transducer with a range of 0-SO0 psig.
Mass Loss. Mass losses were determined by mounting the entire test fire apparatus on an Arlyn Scales Model 501-C **load** cell, range 0-227 kg (0-SO0 Ib).
Temperature. Temperatures were monitored by type K Inconel-sheathed thermocouples (Omega).
Oxygen. Oxygen was monitored at the height of the fire apparatus with a Servomex 540A paramagnetic oxygen analyzer.
Data Acquisition. Data acquisition and treatment was accomplished with the software package LabTech Notebook for Windows, version **8.0.**
Video. All tests were videotaped.

MATERIALS

n-Heptane. Harcros Chemicals, Inc.
Wood. **Kiln** dried spruce, trade size **2** by 2 by 18 in. **long;** water content 9-13%, measured with an Omega moisture tester.
Plastic sheets. Plastic sheets were 16 by 8 by 3/8 in. thick. Cone calorimetry measurements by Hughes Associates, Inc., confirmed that the plastics met the specifications found in the UL2166 and UL 2127 standards.

FIRE SUPPRESSION AGENTS

HFC-227ea. HFC-227ea (FM-200') was Great Lakes Chemical Corporation fire suppression grade
HFC-125. HFC-125 was obtained from DuPont.
HFC-23. HFC-23 was obtained from Great Lakes Chemical Corporation.
NAF-S-III. NAF-S-III was obtained from a NAF-S-III distributor in Italy.
Inergen. Inergen (IG-541) was obtained from an authorized Ansul distributor.
Nitrogen. Zero grade nitrogen obtained from a local vendor (Nordan Smith) was employed.

Select physical property data required for systems design are summarized in Table 1.

TABLE 1. PHYSICAL PROPERTIES OF CLEAN FIRE SUPPRESSION AGENTS.

Agent	MW	Specific Volume Vapor, ft^3/lb @ 1 atm, 70 °F	Agent Content per Cylinder, ft^3 @ 1 atm, 70 °F
FM-200®	170.03	2.2075	
HFC-125	120.02	3.1706	
HFC-23	70.01	5.4814	
NAF-S-III	92.90	4.1621	
Inergen	34.0	11.358	200
Nitrogen	28.0	13.75	183

SUPPRESSION SYSTEMS

HFC-227ea (FM-200®). FM-200®, superpressurized with nitrogen to 360 psig at 70 °F, was discharged from a 200-lb Kidde cylinder (internal volume 2.859 ft^3) equipped with an electronic/manual actuation unit. System design was accomplished with the Kidde Clean Agent Flow Calculation Program, version **K** 2.20, developed by Hughes Associates, Inc. The piping system employed is shown schematically in Figure 2.

The required weight of FM-200® was calculated from the relationship:

$$W = \frac{V}{S} \times \frac{C}{100 - C} \qquad [1]$$

where **W** is the required weight of agent in pounds, C is the desired concentration of agent in% v/v, V is the volume of the enclosure (4061 ft^3), and S is the specific volume of the superheated FM-200® vapor at 1 atmosphere pressure and 70 °F (2.2075 ft^3/lb). Table 2 shows the required quantities of FM-200®.

TABLE 2. FM-200® REQUIREMENTS.

FM-200® % v/v	FM-200® lbs
5.8	113
6.7	132

HFC-125. HFC-125, superpressurized with nitrogen to 360 psig at 70 °F, was discharged from a Kidde 200-lb cylinder equipped with a manual actuation unit. The required weight of HFC-125 was calculated from relationship [1], for the case V=3030 ft^3 and S=3.1706 ft^3/lb. Requirements are shown in Table 3.

HFC-23. HFC-23 was discharged from a 200-lb Kidde-Fenwal DOT-3AA2015 US Navy high pressure Halon 1301 cylinder (USN-KF-13121 US GOVT). The piping system employed is shown schematically in Figure 2. To account for agent left behind in the cylinder, the required weight of HFC-23 was calculated by multiplying the amount of agent calculated from the relationship [1] by 1.1, as suggested in the most recent draft of ISO 14520 [3]. Requirements are summarized in Table 4.

NAF-S-III. NAF-S-III, superpressurized with nitrogen to 360 psig at 70 °F, was discharged from a Kidde 200-lb cylinder equipped with an electronic/manual actuation unit. The piping system employed is shown schematically in Figure 2. The required weight of NAF-S-III was calculated from the relationship [1] (V = 4061 ft^3; S = 4.1621 ft^3/lb). Requirements are shown in Table 5.

Inergen. Inergen was discharged from the required number of 200 ft^3. Inergen cylinders (Ansul part no. 879642) connected to an end draw manifold via 5/8 in. high pressure flex hoses (Ansul part no. 842424). The Inergen cylinders were charged with Inergen to a pressure of 2175 psig; the internal volume of the cylinders is 38.0 **L** (1.34 ft^3). Cylinder actuation was via a manual lever release actuator (Ansul part no.

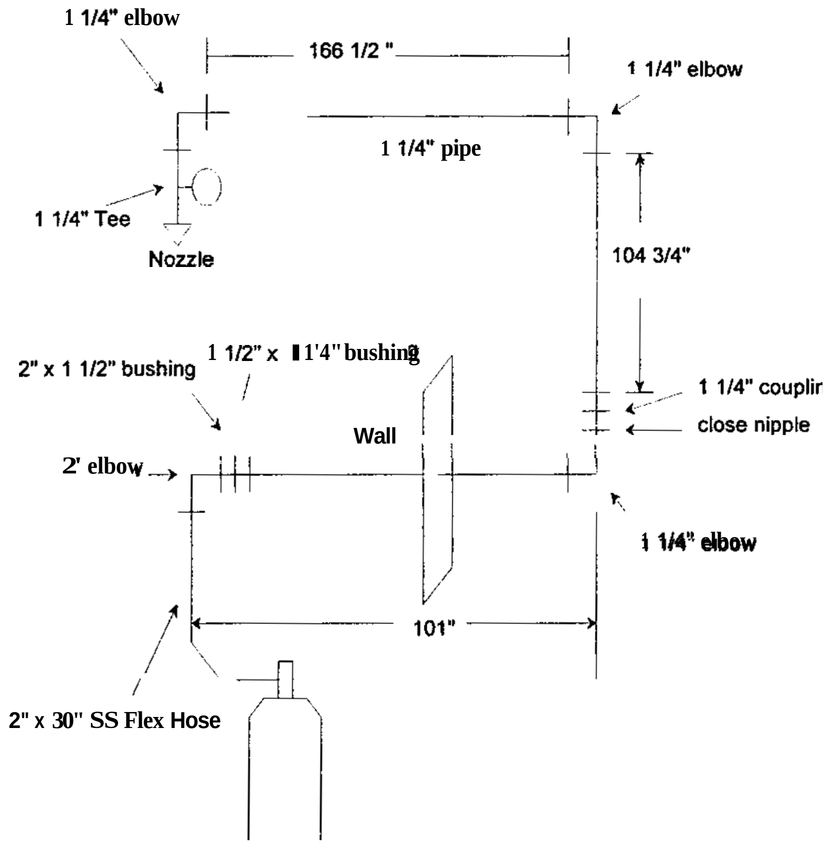

Figure 2. Piping Diagram.

TABLE 3. HFC-125 REQUIREMENTS.

HFC-125% v/v	HFC-125 lbs
6.0	81.1
6.2	84.0
6.4	86.9
6.6	89.8
6.8	92.7
6.9	94.2
7.0	95.7
8.7	121.1
9.0	125.7

TABLE 4. HFC-23 REQUIREMENTS.

HFC-23% v/v	HFC-23 lbs
10.0	90
11.0	101
12.1	112
13.1	123

TABLE 5. NAF-S-III REQUIREMENTS.

NAF-S-III % v/v	NAF-S-III lbs
1.2	86
8.6	92
9.9	107
10.2	111
11.3	124

832098). A 3.18 cm (1.25 in.) orifice union (Ansul part no. 416680), either code 20 or 24, connected the manifold to the remaining pipe network, which consisted of I .25 Schedule 40 pipe (Figure 2). The concentration of Inergen developed in the enclosure was found by solving the following relationship for C:

$$X = 2..303 \bullet V \bullet \log(\frac{100}{100-C}) \qquad [2]$$

where X = ft³ of lnergen discharged (No. of cylinders multiplied by 200 **ft³** lnergen per cylinder), C is the concentration in% v/v, and **V** is the enclosure volume (V = 4061 ft'). The concentration of Inergen as a function of the number of 200 ft³ lnergen cylinders employed is shown in Table 6. Also shown are the predicted **O,** levels resulting from an enclosure concentration of C, calculated from the relationship:

$$\% O_2 = 21.0 - 21.0*(C/100) \qquad [3]$$

TABLE 6. INERGEN QUANTITIES AND CONCENTRATION.

No. Cylinders	Concentration, % v/v	Predicted O_2, % v/v
6	25.6	15.6
7	29.2	14.9
8	32.6	14.2
9	35.8	13.5
10	38.9	12.8
11	41.8	12.2
12	44.6	11.6

Nitrogen. Nitrogen was discharged from the same Inergen cylinders (Ansul part no. 879642) employed in the lnergen tests. The cylinders were pressurized to 2000 psig with nitrogen, corresponding to 183 ft' of nitrogen at 1 atmosphere and 70 °F, calculated from the Ideal Gas Law. The cylinders were connected to an end draw manifold via 5/8 in. high pressure flex hoses (Ansul part no. 842424). Cylinder actuation was via a manual lever release actuator (Ansul part no. 832098). A **3.18** cm (1.25 in.) orifice union (Ansul part no. 416680), either code 20 or 24, connected the manifold to the remaining pipe network, which consisted of 1.25 in. Schedule 40 pipe as shown in Figure 2. The concentration of nitrogen developed in the enclosure was found by solving the following relationship for *C:*

$$X = 2..303 \bullet V \bullet \log(\frac{100}{100-C}) \qquad [2]$$

where X = ft³ of nitrogen discharged (no. of cylinders multiplied by 183 ft³ nitrogen per cylinder), C is the concentration in% v/v, and V is the enclosure volume **(V** = 4061 ft³). The concentration of nitrogen as a function of the number of cylinders employed is shown in Table 7. **Also** shown are the predicted **O,** levels resulting from an enclosure concentration of C, calculated from relationship [3].

TABLE 7. NITROGEN QUANTITIES AND CONCENTRATION.

No. Cylinders	Concentration, % v/v	Predicted O_2, % v/v
6	23.7	16.0
7	27.0	15.3
8	30.3	14.6
9	33.3	14.0
10	36.3	13.4
11	39.1	12.8
12	41.8	12.2

EXPERIMENTAL PROCEDURE

Halocarbon Agents. The procedures employed for the evaluation of the halocarbon agents FM-200®, HFC-23, and NAF-S-III are described in the draft UL document ***UL 2166: Proposed First Edition of the Standardfor Halocarbon Clean Agent Extinguishing System Units*** [1].

Inert Gas Agents. The procedures employed for the evaluation of the inert gas agents are described in the UL document ***UL 2127: Proposed First Edition of the Standardfor Inert Gas Clean Agent Extinguishing System Units*** [2].

RESULTS AND DISCUSSION

The Class A and heptane minimum extinguishing concentrations determined in this study are compared with the values from the ISO standard 14520 [3] in Table 8. As can be seen in Table 8, the minimum extinguishing concentrations measured in this study are in general in good agreement with the values listed in the appropriate ISO standard [4–9].

TABLE 8. PERFORMANCE OF FIRE SUPPRESSION AGENTS.

	Class A Minimum Extinguishing Concentration, % v/v		n-Heptane Extinguishing Concentration, % vlv	
Agent	ISO 14520	This work	ISO 14520	This work
FM-200®	5.8	5.8	6.6	6.7
HFC-125	—	—	8.7	9.0
HFC-23	15.0	11.0	12.0	13.1
NAF-S-III	7.2	10.2	9.9	9.9
Inergen	28.1	32.6	29.1	29.2
Nitrogen	—	33.3	33.6	27.0

The most difficult Class A fires for the halocarbon agents were the PMMA sheet fires, which require the highest extinguishing concentrations of the Class A fuels tested. In contrast, for the inert gas agents the most challenging test was found to be the wood crib fire. At concentrations capable of readily extinguishing the plastic sheet fires of UL 2127, the inert gas agents were unable to provide sufficient cooling to prevent reignition of the wood crib following a 10-min soak period. Although flaming combustion is halted, the cribs smolder and are hot enough after a 10-min soak that reignition will occur upon exposure to fresh air. This behavior is consistent with the lack of cooling (low heat absorption characteristics) of the inert gas agents compared to the halocarbon agents, which due to their high heat capacities are able to afford more cooling.

The Class A plastic sheet fires described in UL 2166 and UL 2177 range in fire size from approximately 15 kW for the ABS fires to approximately 30-40 kW for the PMMA fires. It should be noted that such fire sizes are much greater than the fire sizes expected to be encountered in real world Class A applications of the clean agents. As a result, the UL tests can be regarded as representative of a worst-case scenario. Industry studies have noted that fires in telecommunication facilities, the major application area of the clean agents, involve small quantities of materials burned and small areas of fire damage [10, 11]. The types of fires characteristic of telecommunication facilities have been discussed in detail [12]. Fire hazards in such facilities are characterized by low fuel loads, and include wire insulation, printed circuit boards, electronic components, transformers, insulating materials and plastic housings. As indicated by Meacham [12], fires in such facilities are of low energy output, often less than 5-10 kW in size.

Detection systems employed in telecommunication facilities are designed to detect fires in their incipient stages, and there is an industry wide desire to detect fires at as small a size as possible. Telecommunication industry leaders such as Bellcore, AT&T, and Bell Atlantic have indicated their desire for detection of typical equipment fires in telecommunications facilities at a fire size of 1 kW; whereas for highly sensitive equipment, detection at a fire size of 0.1 kW is desirable [13]. Detector selection for the telecommunications industry can be based upon the level of damage tolerable [14]. It should be noted that in this evaluation fires larger than 10 kW are considered to result in a major loss (Table 9). Given the small fire sizes involved, and the level of detection desired by the industry, the UL 2166 and 2127 Class A fire tests clearly are representative of a worst-case scenario.

TABLE 9. DETECTION DEVICE SELECTION BASED ON ACCEPTABLE LOSS.

Acceptable Loss	Fire Size	Suitable Detection Device
Major loss	10 kW or greater	Standard or fast response sprinkler head **Spot** type heat detection device
Large Loss	5 - 10 kW	Spot or linear beam detector at "listed" spacing Line type heat detector
Moderate Loss	2 - 5 kW	Spot or linear smoke detectors at reduced spacing or within equipment In-duct smoke detectors
Small loss	Less than 2 kW	Incipient (air sampling) detection system

REFERENCES

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