EXAMINATION *AND* COMPARISON OF EXISTING HALON ALTERNATIVES AND NEW SUSTAINABLE CLEAN AGENT TECHNOLOGY IN SUPPRESSING CONTINUOUSLY ENERGIZED FIRES

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ABSTRACT

This paper describes the results from testing the effectiveness of halon alternatives in extinguishing a tire scenario representing continuously energized electrical equipment. Three likely modes of failure in telecommunications facilities have been identified and three fire tests to examine these scenarios have been developed.' Objectives of this study were to replicate and verify that extinguishment could be accomplished using HFC-227ea design concentrations at and slightly lower than the minimum cup-burner level and to assess the ability of 3M Company's experimental product L-15566 in suppressing tires using the Conductive Heating Test protocol from their report. An additional goal was to evaluate the effect of a constant electrical arc or ignition source above the sample using these same extinguishing agents and design levels.

INTRODUCTION

The National Fire Protection Association (NFPA) Standard 2001, *Standard for Clean* Agents, provides guidelines for the design and installation of clean agent total-flooding systems as determined by the consensus standards writing process. It is this standard that provides necessary information to system designers as to the properties of the agents and system installation guidelines including appropriate design concentrations. Minimum design concentrations specified in NFPA 2001 are determined for either Class A or Class B fuel fires. Currently, no standard test method exists, which are agreed upon by industry leaders, to provide a fair representation of a Class C, energized electrical fire event. As a result, guidance for designing a system to protect electrical equipment areas where de-energizing the equipment is not an immediate option has been limited to the following suggestion found in the 1996 Edition, Appendix, NFPA 2001.

> A-3-7: Energized electrical equipment that might provide a prolonged ignition source should be de-energized prior to or during agent discharge. If electrical equipment cannot be de-energized, consideration should be given to the use of extended discharge, the use of higher initial concentration, and the possibility of the formulation of combustion and decomposition products [1].

Test methods have been developed during the past several years in efforts to quantify this phenomenon and include energized wires surrounding polymethylmethacrylate (PMMA) [2, 3], energized wires across the top of the cup-burner apparatus [4], hot metal surfaces [5], and radiant conical heaters [6]. However, the most recent tests conducted utilized various electrical cables placed inside a circular electric heater to replicate an overheated connection achieved by passing high current through small cable bundles placed between copper bus bars [7].

New test data from the **two** most recent test methods mentioned above has been included in Appendix A-3-6 of NFPA 2001, 2000 Edition [7]. This information indicates that design concentrations as low as 5.2% and 5.0% [V/V] of HFC-227ea are capable of extinguishing and preventing re-ignition of energized cable fires using the Conductive Heating Test and Ohmic Heating Test protocols, respectively.

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* McKenna, L.A. Jr., Gottuck, D.T., DiNenno, P.J., and Mehta, S., "Extinguishment Tests of Continuously Energized Class C Fires Using HFC-227ea (FM-200)," Submitted to NFPA 2001 Technical Committee on Halon Alternative Protection Options, 1998. Copy on file with the author.

In an effort to expand and confirm that data, results from testing this test series confirms that HFC-227ea concentrations at or near cup-burner levels can extinguish the energized fire scenarios using the original test protocols. However, higher design concentrations were required to extinguish the same fire scenarios effectively when an electric arc source was added for the ignition source. This method, identified as the Modified Conductive Heating Test Protocol, will be described later in this report. This report presents current results from the Conductive Heating Tests while using extinguishing agents HFC-227ea and L-15566. These agents were also utilized during the Modified Conductive Heating tests, and the outcome of those tests is also included. Tests using the Ohmic Heating Test protocol are still in progress so a complete data set is not yet available.

TEST EQUIPMENT

TESTING ENCLOSURE & DISCHARGE SYSTEM

Tests were performed in a 1.28 m^3 (45 ft’) enclosure having dimensions 0.91 x 0.91 x 1.52 m (3 x 3 x 5 ft). This enclosure was constructed with 13 mm (0.5 in.) thick polycarbonate walls held in place by a 5 cm (2 in.) angle iron frame. Two removable doors, equipped with four vise grip style compression latches, provide access to the inside of the enclosure. The doors are 29.5 x 29.5 cm (11.6 x 11.6 in.) in dimension and overlap the perimeter of the opening 3.3 cm (1.3 in.).

Two openings in the enclosure allow ventilation of the decomposition products after a test is completed. The first opening, located 7.6 cm (3 in.) from the bottom left hand comer, allows makeup air into the enclosure. A second opening in the upper right hand comer on the opposing side is located 7.6 cm (3 in.) down from the top surface and serves as the exhaust vent. Both openings are 5 cm (2 in.) in diameter.

The ventilation system is controlled manually by activating three separate solenoid valves. The first two solenoid valves open or close the inlet and exhaust vents. The third solenoid valve operates a Dayton Shaded Pole Blower capable of providing 24 L/s (50 ft^3/min) of outside ambient air. This blower is installed on the inlet opening. This facilitates post-test purging of gases in the enclosure and supplements the negative exhaust system on the outlet vent.

Extinguishing agent was discharged into the enclosure through a simple pipe network constructed from 6.4 mm (0.25 in.) diameter schedule 40 pipe and fittings. The total length of the discharge system piping was roughly 85 cm (33.5 in.). A 1000 cc (0.035 ft’) stainless steel cylinder fitted with Schrader valve and a 90 deg needle valve was used to achieve the range of agent concentrations needed. The valves facilitated filling and transporting the cylinder from the fill area to the enclosure. A Worcester Controls quarter turn ball valve is located 10 cm (4 in.) downstream of the cylinder-initiated discharge of agent. The nozzle used in the enclosure was a Bete 0 deg NF2000 nozzle. The discharge system was not optimized for any specific agent, but was designed to accommodate both of the agents tested.

To prevent the extinguishing agent from directly impinging on the test specimens, a polycarbonate baffle system, 6.4 mm (0.25 in.) thick, was constructed and placed in the middle of the floor in the test enclosure. Low-density calcium silicate board was placed on top and bottom of the baffles. Details of this setup can be seen in Figure 1.

DATA ACQUISITION EQUIPMENT

Internal cylinder pressure and discharge pressures and temperatures were recorded with a computer controlled analog-to-digital converter. The computer system is a 133MHz Pentium based Toshiba running the LabTech Notebook data collection program. A parallel port cable is used as an interface to control an Omega OMB-Daqbook 100 analog-to-digital converter; a three-slot expansion chassis containing two DBK-19 thermocouple input boards and a DBK-I3 digital input board was daisy chained to the Daqbook.

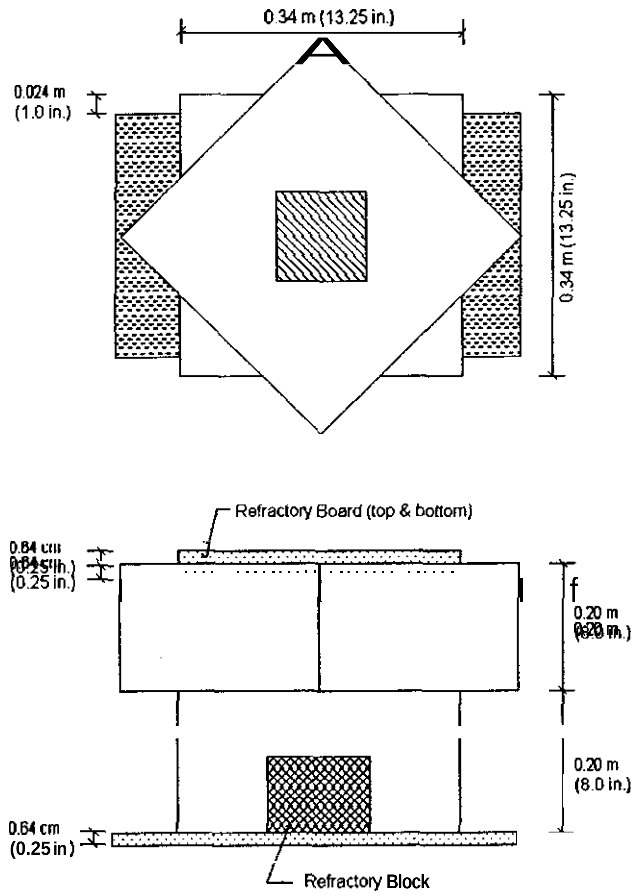

Figure 1. Details of baffle in enclosure

Thermocouples were used to measure the temperatures developed inside of the test enclosure and on the top surface of the cable and wires during the tests. Starting **10** cm **(4** in.) from the top of the test enclosure and spaced **30.5** cm **(12** in.) apart were four **3.2** mm **(0.13** in.) diameter stainless steel, exposed tip thermocouple probes. The orientation of the probes formed a thermocouple tree in the centerline of the enclosure. A similar **3.2** mm (0.13 in.) diameter stainless steel, exposed tip thermocouple probe was used to measure the temperature on the surface of the cable during the Conductive Heating Tests.

Three types of pressure transducers were used to measure the cylinder and discharge pressures during the test series. An Omega pressure transducer, model no. **PX102-500SV** (0-500 psi range), was used for tests utilizing discharge pressures of **2482** kPA **(360** psi) and **1379 kPA (200** psi). For all tests using a discharge pressure of 690 kPA **(100** psi), **two** different pressure transducers were installed. The first one, model no. **PX242-250G5V (0-250** psi), was installed on the cylinder, while the second (model no. PX242-150G5V [0-150 psi]), was installed near the nozzle.

TEST METHODOLOGY AND PROCEDURE

This series of tests was conducted according to the protocol for vertical tests developed by Hughes Associates, Inc., and is intended to demonstrate an event where current continues to flow through a loose connection. To accomplish this, heat is conducted directly to hare conductors of **350** mcm cable, typical of supplying large amounts of power.

Two separate cable types manufactured by Lucent Technologies were tested: type KS-5482L and type **KS** 20921. The heat was provided by a Watlow "K-Ring" heater (model SKR2210201A), capable of providing 1000 Watts of energy while operating on 240 VAC. The heater **is** equipped with an integral thermocouple connected to a 240 VAC Watlow (model 93AA-1CAO-00RG) 1/8 DIN temperature ramping controller. This was used to replicate and control the output of the heater during the tests,

The cable **was** rolled off the supply spools onto the floor for straightening. Test specimens were prepared by cutting smaller segments to a length of ***260*** mm (10.25 in.) and removing 108 mm (4.25 in.) of insulation from one end to expose the bare copper conductors. The rest of the test procedure is as follows.

The required amount of extinguishing agent was determined using the following equation [8]

$$m = \rho V\left(\frac{C}{100 - C}\right) \quad \text{where,} \tag{1}$$

m = amount of agent [kg]

p = vapor density [7.26 **kg/m³** at 21 °C]

V = open volume of the test enclosure [$1.28 m^3$]

C = desired concentration [%]

- The cylinder is filled with the appropriate amount of agent to reach the desired extinguishing concentration and pressurized to the desired pressure with nitrogen. Next, it **is** placed in its holding bracket on the test enclosure and attached to the discharge piping.
- The mass ***of*** the specimen is determined prior to the test.
- The bare conductor end of the cable specimen is placed into the "K-Ring" heater. A nail is pushed into the conductors to provide a firm fit between the conductors and inner wall of the heater.
- The heater and cable specimen are placed in the bottom of the test enclosure, in a vertical position and on top of a 1000 cm^3 refractory block. The top baffle is placed around the heater.
- A thermocouple is inserted into the baffles and rests on top of the copper cable conductor. The calcium silicate board is placed on top.
- The test placard is completed identifying the test details and filmed with the video recorder.
- The data acquisition system, camera, and heater are activated. The controller for the heater is set to 900 °C; this setting is maintained until 10 min after discharge.
- When the temperature for the thermocouple placed on top of the copper conductors of the cable reaches 310 °C, a pilot flame is applied to the base of the exposed portion of the cable.
- Once sustained ignition occurs, the test enclosure is sealed and the ventilation system turned off.
- The extinguishing agent is discharged one minute after sustained ignition.
- The experimental setup is observed for 10 min after discharge, the heater is turned off, and the ventilation system is turned on. The heater is allowed to cool prior to starting setup for next test. The sample is removed and the **mass** determined after test.

Additionally, during the early stages of this study **a** small number of screening tests were conducted. These tests were done to evaluate the length of time the cable specimens would burn once ignited by the gas pilot and to see if the test specimens could be driven to autoignition by the heater alone. For these tests, the same cable specimens were prepared; however, no extinguishing agent was discharged.

MODIFIED CONDUCTIVE HEATING TESTS

It was the intent of this study to provide an alternative to the gas pilot used in the previous test protocol that would provide a continual ignition point during the entire test. Building on the protocol specified above, an electrical arc source was affixed above the cable specimens to provide this continual ignition point throughout the entire holding period. The inclusion of this electric arc ignition source in a modified test procedure improves upon the previous test protocol by allowing evaluation of situations in which conductive heating of cable connections occurs in close proximity to an arc that develops between electrical equipment.

A Dongan transformer rated at 6000 V, 20 mA provided the source for the electrical arc. In an effort to prevent fouling between arc probes and potentially losing the arc source, an arc source was developed between the conductors of the cable and a probe above the top surface of the cable.

Prior to inserting the bare conductors into the "K-Ring" heater, the centermost strand was separated and twisted perpendicular to the side of the cable while the remaining strands were inserted. One of the leads from the Dongan transformer was connected to this centermost strand, which now protrudes to the side. A second wire attached to the remaining transformer terminal was clipped onto a 3.2 mm (0.13 in.) steel probe and positioned 10-16 mm (0.38-0.63 in.) above the top surface of the cable.

Figure 2 provides a schematic of the cable specimen, the heater and locations of the arc source, and thermocouple.

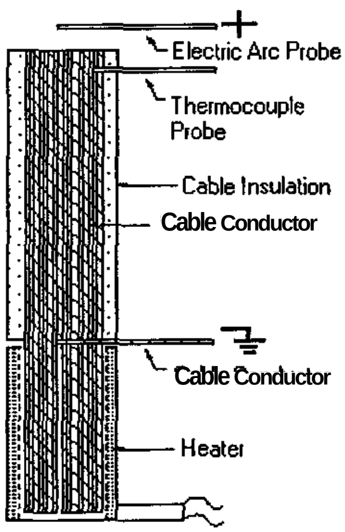

Figure 2. Test setup for modified conductive heating test.

Although this test arrangement provided a sufficient luminous, a bluish colored electric arc between the metal conductors, the additional electric energy created problems while monitoring temperatures on the top surface of the cable. These temperature measurements were considered important for comparisons between the two test methods. To mitigate this effect, a small hole was drilled through the cable insulation approximately 6.4 mm (0.35 in.) down from the top. The tip of the thermocouple probe was inserted into this hole so that the probe was in direct contact with the copper conductor strands.

RESULTS

CONDUCTIVE HEATING TESTS

Observations made during the initial set of Conductive Heating Tests indicate that extinguishment below the minimum design concentration of 7.0% [V/V] in a 1.28 m^3 test enclosure is possible when using HFC-227ea. In fact, concentrations of 6.0 and **4.1%** [V/V] were capable of extinguishing the fires and preventing reignition. However, two issues of concern with the test protocol were raised when autoignition was never achieved during any of the Conductive Heat Tests; even with the heater set to its maximum power output and when concentrations as low as 1.8% [V/V] effectively extinguished and prevented reignition of specimens ignited by a gas pilot source. Tests were replicated at low design concentration **of** 1.8% [V/V] HFC-227ea for each cable type, which continually extinguished and prevented reignition (tests COND004, COND006, & COND041) in all tests. It is presently unknown whether the turbulence from discharge or the cooling effect of the extinguishing agent had the greater effect on the flame.

Table 1 provides a summary of results from this phase of testing. At no time during this phase did autoignition occur as a result of the heat provided solely from the heater. In fact, a number of characterization tests were performed during the early stages of this study, which included setting the heater at its maximum set point to try and reach autoignition. The only observation made was that the insulation material off-gassed until the remaining material still attached to the cable could not even be ignited by an externally added pilot source.

TABLE I. SUMMARY OF SELECTED HFC-227EA CONDUCTIVE HEATING TEST RESULTS.

Test	Agent Tested	Cable Type	Test Orientation	Design Concentration [%]	Discharge Pressure [kPa]	Ignition Source	Autoignition Achieved [Yes/No]
COND001			Vertical	6.0	2482	Pilot	No
CONDO38			Vertical	5.6	655	Pilot	NO
COND011	HFC-227ea	KS-5482L28FR	Vertical	4.1	1345	Pilot	No
CONDO44			Vertical	3.0	655	Pilot	No
CONDO04			Vertical	1.8	**2482**	Pilot	No
CONDO39			Vertical	5.6	655	Pilot	No
CONDO13			Vertical	4.0	1345	Pilot	No
CONDO45	HFC-227ea	KS-20921L2	Vertical	3.0	655	Pilot	No
COND041			Vertical	1.8	655	Pilot	No
CONDO05			Vertical	1.8	2482	Pilot	NO

At the present time, testing with L-15566 has only been performed at a concentration **of** 3.5% [V/V]. This value was determined to be the minimum extinguishing concentration for propane **as** determined in the cup burner and thus served **as** a useful starting point in this evaluation of suppressing energized tires. Table 2 presents a summary ***of*** L-15566 test results.

Table **3** provides additional testing information for tests listed in Tables 1 and 2. Generally, times to ignition appear to be in the low to mid 600-sec ranges where the time to extinguishment varied from 5 to just under 300 see.

Just **as** there were no instances of autoignition using this protocol, reignition of the cable specimens never occurred after discharge of the extinguishing agent or during the hold time period. As an additional exercise and to verify that fuel existed for combustion to take place, the enclosure was opened and the gas pilot source was inserted at the base of the cable specimen after the time period to determine whether the

TABLE 2. SUMMARY OF SELECTED L-15566 CONDUCTIVE HEATING TEST RESULTS.

Test	Agent Tested	Cable Type	Test Orientation	Design Concentration [%]	Discharge Pressure [kPa]	Ignition Source	Autoignition Achieved [Yes/No]
CONDO62	L-15566	KS-5482L28FR	Vertical	3.5	2482	Pilot	No
CONDO65			Vertical	3.5	1345	Pilot	No
CONDO67			Vertical	3.5	655	Pilot	No
CONDO58	L-15566	KS-20921L2	Vertical	3.5	1345	Pilot	No
CONDO60			Vertical	3.5	655	Pilot	No
CONDO61			Vertical	3.5	2482	Pilot	No

TABLE 3. DETAILS OF SELECTED CONDUCTIVE HEATING TESTS.

Test	Agent Tested	Cable Type	Design Concentration [%]	Ignition [s]	Discharge Time [s]	Time of Initial Ext. [s]	Reignition [Yes/No]
COND001	HFC-227ea	KS-5482L28FR	6.0	390	462	473	No
CONDO38			5.6	500	600	615	No
COND011			4.1	659	746	746	No
CONDO44			3.0	610	670	805	No
CONDO04			1.8	613	686	709	No
CONDO62	L-15566	KS-5482L28FR	3.5	621	708	721	No
CONDO65			3.5	622	706	716	No
CONDO67			3.5	687	773	800	No
CONDO39	HFC-227ea	KS-20921L2	5.6	750	810	845	No
COND013			4.0	626	714	736	No
COND045			3.0	620	680	906	No
COND041			1.8	655	715	831	No
CONDO05			1.8	600	647	710	No
CONDO58	L-15566	KS-2092IL2	3.5	633	718	769	No
CONDO60			3.5	605	689	794	No
COND061			3.5	611	694	707	No

inerting capability was complete. In every instance this was done, the cable reignited, verifying that not all ofthe combustibles were driven out of the specimen during the heating period.

MODIFIED CONDUCTIVE HEATING TESTS

Subsequent Conductive Heating Tests with the arc source in place yielded a different outcome. Results show difficulties in extinguishment and preventing reignition using design concentrations between **5.3** and **8.0%** [V/V] for HFC-227ea. Although the sustained fire is extinguished after discharge, small flames develop on the cable during an inerting period indicating that higher design concentrations may be needed to prevent re-ignition.

In comparison with the Conductive Heating Tests, results and observations made during this phase of the project clearly indicate that a higher design concentration is needed to initially suppress and prevent re-ignition when the electric arc source is used. Temperature data collected and compared show that heating of the cable was not exacerbated by the electric arc. Additionally, the electric arc source provided a constant ignition point, sufficient to ignite the volatizing gases at the start of the test and sustain sufficient energy during the inerting hold time period of the test, whereas small flames developed **on** the top of the cable specimens when lower extinguishing concentrations were used.

Comparisons of temperature data, taken from the thermocouple located at the top of the cable specimen were made in effort to determine whether the electric arc had an additional effect on the heating rate of the cable conductors. Figure 3 displays results averaged from six tests conducted using both the original and modified protocols. Three series of data (tests COND002, COND004, and COND044) were used to obtain the profile for the tests using a gas pilot **as** an ignition source while three additional series of data (tests COND022, COND023, and COND053) were used to obtain the profile for tests where the electric arc was used.

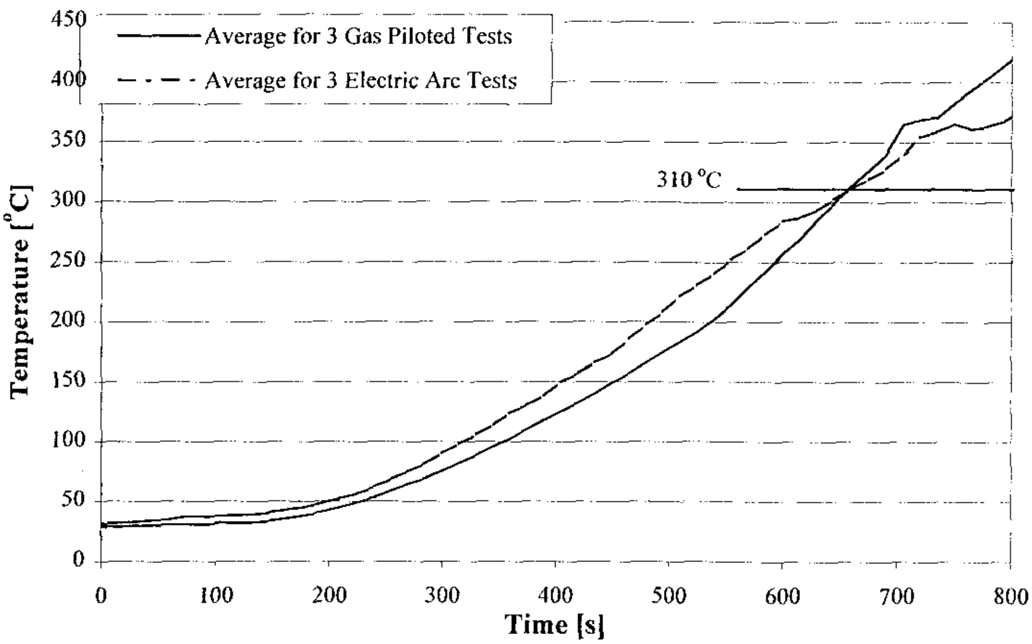

Figure 3. Comparisons of cable temperatures (Cable KS-5482L28FR).

The data presented in Figure 3 indicate that neither the location of the thermocouple between the two test protocols nor additional energy provided by the electric arc source impacted the overall result. Although the temperature in the tests using the electric arc rose faster than tests using the original procedure, the times needed to reach **310** °C were nearly identical. After determining that the addition of the electric arc would not impact the severity of the test, extinguishment tests were performed. Tables 4 and 5 summarize selected Modified Conductive Heating Tests using HFC-227ea and L-15566 **as** the extinguishing agent. **As** the tables indicate, tests were performed using the typical 2482 kPa **(360** psi) cylinder pressure and lower pressures of 1345 kPa (195 psi) and 655 kPa (95 psi). The lower pressures were used **to** evaluate the possibility of turbulence within the enclosure **as** a factor **in** the process of extinguishment **as** opposed to the actual physical and cooling mechanism. The tables also illustrate that in **all** cases where the electric arc source was used, the pyrolizing gases were self-ignited by the arc and the manual insertion of a pilot was not necessary.

While the arc source was sufficient to ignite the pyrolizing gases, the point at which sustained ignition occurs remains rather subjective. In the original test protocol, the gas pilot is inserted at the bottom of the cable near the interface of the K-Ring heater. **As** a result, when ignition occurs, nearly the entire surface of the cable starts burning. In the case where the electric arc source is used, a small flame appears on the top surface of the cable and does not always ignite the vapors rising up the sides of the cable. Since the

TABLE 4. SUMMARY OF SELECTED MODIFIED CONDUCTIVE HEATING TEST RESULTS.

Test	Agent Tested	Cable Type	Test Type/ Orientation	Design Concentration [%]	Discharge Pressure [kPa]	Ignition Source	Autoignition Achieved [Yes/No]
COND024	HFC-227ea	KS-5482L28FR	Vertical	5.6	2482	Electric Arc	Yes
COND053			Vertical	5.6	655	Electric Arc	Yes
COND025			Vertical	7.0	2482	Electric Arc	Yes
COND051			Vertical	8.0	655	Electric Arc	Yes
COND052			Vertical	8.0	655	Electric Arc	Yes
COND050			Vertical	11.0	655	Electric Arc	Yes
COND023			Vertical	11.0	2482	Electric Arc	Yes
COND026	HFC-227ea	KS-20921L2	Vertical	5.3	2482	Electric Arc	Yes
COND015			Vertical	5.6	2482	Electric Arc	Yes
COND021			Vertical	7.0	2482	Electric Arc	Yes
COND020			Vertical	8.0	2482	Electric Arc	Yes
COND047			Vertical	8.0	655	Electric Arc	Yes
COND048			Vertical	8.0	655	Electric Arc	Yes
COND017			Vertical	11.0	2482	Electric Arc	Yes
COND049			Vertical	11.0	655	Electric Arc	Yes

TABLE 5. SUMMARY OF SELECTED MODIFIED CONDUCTIVE HEATING TEST RESULTS.

Test	Agent Tested	Cable Type	Test Type/ Orientation	Design Concentration [%]	Discharge Pressure [kPa]	Ignition Source	Autoignition Achieved [Yes/No]
COND069	L-15566	KS-5482L28FR	Vertical	3.5	2482	Electric Arc	Yes
COND071			Vertical	3.5	1345	Electric Arc	Yes
COND074			Vertical	3.5	2482	Electric Arc	Yes
COND068	L-15566	KS-20921L2	Vertical	3.5	2482	Electric Arc	Yes
COND075			Vertical	3.5	2482	Electric Arc	Yes
COND077			Vertical	3.5	1345	Electric Arc	Yes

flame is relatively small in nature, it sometimes disappears while the enclosure is being sealed. When this occurred, the door to the enclosure was reopened until a stronger flame developed on the cable.

Furthermore, some complexities arose (ambiguity existed) in evaluating the point of extinguishment after discharge of the agent, which were due in part to the discharge agent obscuring visibility. During some tests, the arc source and flame would completely disappear shortly after discharge and then reappear followed by a small localized flame surrounding the arc. When visible, this flame varied in size and duration from test to test.

Based on these variable uncertainties, criteria were established so that each test would be observed and the results would be consistent. After discharge of the agent, if the flame remained or diminished in intensity and remained as a small-localized flame around the arc source, then the overall result was that the fire was not extinguished (Did Not Extinguish, DNE). If the flame was extinguished and only a blue arc source was visible, the fire was deemed extinguished but the arc source remained. If the flame was extinguished and small localized flames were visible around the arc source shortly thereafter, this concentration was considered to have extinguished the fire even though reignition occurred. When the flame and arc source were no longer visible and remained nonexistent throughout the duration of the inertion period, this particular concentration was considered capable of extinguishment and preventing reignition.

Using the criteria established above, Tables 6 and 7 were developed to display detailed results based on the tests listed previously in Tables 4 and 5. In comparison, design concentrations between 5.6-8.0% (V/V) for HFC-227ea were originally capable of extinguishing the fire and preventing reignition using the initial protocol, but did not extinguish **all** of the modified protocol fires.

TABLE 6. DETAILS OF SELECTED MODIFIED CONDUCTIVE HEATING TESTS.

Test	Agent Tested	Cable Type	Design Concentration [%]	Ignition [s]	Discharge Time [s]	Time of Initial Ext. [s]	Reignition [Yes/No]
CONDO24			5.6	534	606	DNE	DNE
CONDO53			5.6	615	675	DNE	DNE
CONDO25			7.0	537	608	848	Yes
CONDO51	HFC-227ea	KS-5482L28FR	8.0	603	663	DNE	DNE
CONDO52			8.0	690	750	766	No
CONDO50			11.0	555	615	639	Yes
CONDO23			11.0	510	580	702	Yes
CONDO26			5.3	498	578	DNE	DNE
CONDO15			5.6	486	530	DNE	DNE
CONDO21			7.0	509	582	DNE	DNE
CONDO20	HFC-227ea	KS-20921L2	8.0	483	543	661	Yes
CONDO47			8.0	536	596	615	No
CONDO48			8.0	587	647	DNE	DNE
COND017			11.0	460	532	832	No
CONDO49			11.0	495	555	584	No

TABLE 7. DETAILS OF SELECTED MODIFJED CONDUCTIVE HEATING TESTS.

Test	Agent Tested	Cable Type	Design Concentration [%]	Ignition [s]	Discharge Time [s]	Time of Initial Ext. [s]	Reignition [YesMo]
CONDO69			3.5	790	860	923	Yes
CONDO71	L-15566	KS-5482L28FR	3.5	638	706	713	Yes
CONDO74			3.5	955	1015	1022	Yes
CONDO68			3.5	512	597	607	No
CONDO73	L-15566	KS-20921L2	3.5	570	640	649	No
CONDO77			3.5	560	620	638	Yes

Related results of tests using L-15566 were compared, although tests were only performed at one extinguishing concentration. The concentration ***of*** 3.5% (V/V) was chosen **as** the starting point for testing **as** this value was found to he the minimum extinguishing concentration in **a** micro cup-burner apparatus using propane as the fuel. L-15566 was successful in preventing reignition in two of the tests listed above (Table 7); however, it did not prevent reignition in any ofthe tests using the cable with added fire resistive materials. Initial testing with this extinguishing agent shows inconsistent extinguishing capacity at this level, and additional testing is recommended for its use in energized fire events.

DISCUSSION *AND* CONCLUSIONS

The first phase of these tests confirmed the outcome oftesting performed by Hughes Associates, Inc., in that concentrations lower than ordinary design values are capable of extinguishing a particular fire scenario. However, when the electric arc source was added during the second phase of this study, the same extinguishing concentrations were not as successful in extinguishing the fire and preventing reignition. This modified protocol emphasizes that higher design concentrations are needed in situations where internal heating may occur and the likelihood or possibility that an external ignition source is in close proximity.

The fundamental reason for the addition of the electric arc was to create a scenario in which a fire may develop when a cable undergoes internal heating and is in close proximity to an external ignition source. The ignition source in this case could be considered as an arc developing from a loose connection. In any event, the tests provide an awareness that additional testing and research should continue on this particular design issue to offer appropriate levels of guidance for system designers in the near future.

Results indicate that elevated extinguishing concentrations above cup-burner levels are needed for the effective use of HFC-227ea in this modified test protocol, when HFC-227ea is utilized as the extinguishing agent for protection of Class C fire hazards. Testing also indicates that extinguishment is possible with reasonable quantities of L-15566, although additional testing is necessary at higher concentrations to determine accurately the appropriate upper level extinguishing concentration necessary to prevent reignition consistently.

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