INNOVATIVE DEVELOPMENTS IN THE DESIGN AND VERIFICATION OF AN FE-13™ ENGINEERED FIRE SUPPRESSION SYSTEM

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INTRODUCTION

The development of an engineered fire suppression system is a complex endeavor. involving rigorous testing, thorough documentation, including writing complete instructions for system design. installation, operation and maintenance. In testing these systems, listing and approvals agencies require the system to perform in accordance with recognized industry standards. In the case of a clean agent, engineered fire suppression system, there are three critical parameters that must be measured in each agent discharge test. In turn, the software calculation routine must accurately predict, within a specified tolerance, each of these parameters, for a given test.

(a) Discharge time
The system discharge time must be predicted by the software calculation program within ±1 sec, of the measured result.

(b) Average nozzle pressure
Nozzle pressures measured using pressure transducers during the agent discharge. The arithmetic mean of the data, over the time defined by the calculated discharge time, at each nozzle is calculated. The average nozzle pressure must be predicted by the software calculation program within ± 10% of the measured result.

(c) Agent mass discharged
The agent mass discharged from each individual nozzle, is measured (see DISCHARGE TESTING REQUIREMENTS AND TECHNIQUES for details). The agent mass must be predicted by the software calculation program within +10 and -5% of the measured result.

In addition to the three measured parameters, each individual test is defined by maximum and minimum values for a variety of system and piping parameters, referred to as the software's "limits." The majority of these system limits for engineered flow testing are shown below.

- Percent Agent in pipe
- Nozzle orifice area vs. inlet pipe area (a/a ratio)
- Pipe flow rates
- Percent Pipe before 1st tee
- Liquid arrival and run-out imbalance
- Tee split ratios
- Container fill density
- Pipe types and pipe schedules
- Elevation changes (see CALCULATION OF DISCHARGE TIME for additional details)

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The values for these limits are quantitatively determined by both the flow calculation program and the measurement of the piping system geometry. These values are not used in pass/fail criteria, but are used to establish the limitations of the flow calculation software, in each category. The following sections detail the unique and innovative methods used to meet the specified criteria for acceptance, outlined above.

CALCULATION OF DISCHARGE TIME

As introduced above. the discharge time is one of the critical parameters used as part of the pass/fail criteria for a given discharge test, and ultimately the flow calculation software itself. The discharge time is defined in the requirements of NFPA 12A (Standard on Halon 1301 Fire Extinguishing Systems), and echoed in NFPA 2001 (Standard on Clean Agent Firc Extinguishing Systems): 95% of the required agent mass be delivered in 10 sec or less for halocarbon agents.* While the time when this quantity of mass has been delivered can be predicted as well as any other event during the discharge, experimental verification is a challenging problem. Direct measurement of the cumulative mass discharged from a nozzle is nearly impossible as the reaction forces caused by the fixed/restrained nozzle and the thrust of the agent leaving the nozzle would have to be overcome; measurements must still be made (with reasonable accuracy) when only 5% remains to be discharged from multiple nozzles of various sizes.

In the past, with other agents such as bromotrifluoromethane (Halon 1301) and heptafluoropropane (FM-2000). nozzle liquid run-out has been used **as** an indication of when the 95% **mass** discharge requirement has been achieved. An inflection in the nozzle pressure trace occurs as the flow changes from predominately liquid to predominately vapor. Figure 1 shows an example of this characteristic feature of the pressure trace for FM-200.

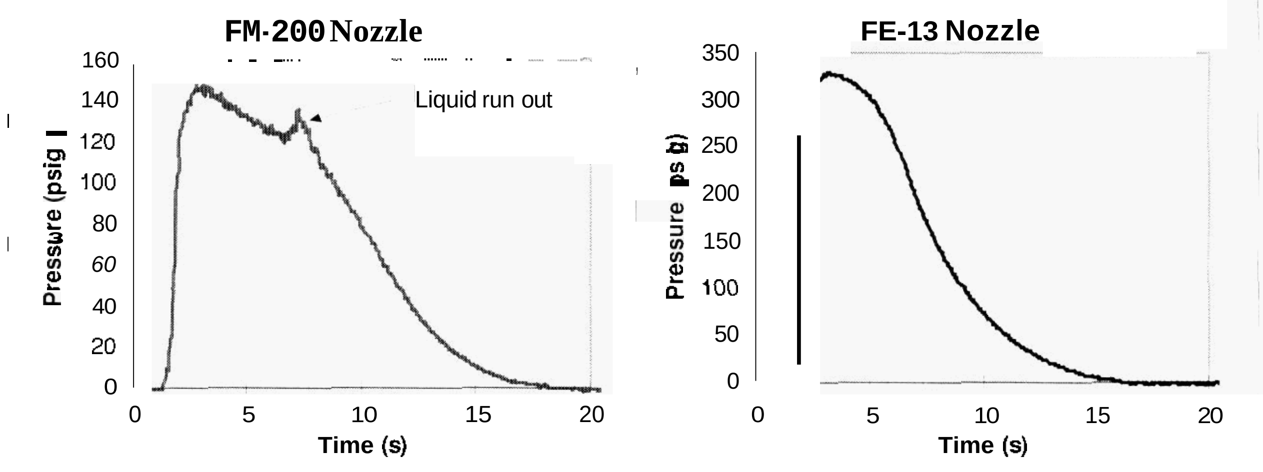

Figure 1. FM-200 / FE-13 nozzle pressure trace, showing liquid run-out

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* More specifically, "The discharge time period is defined as the time required to discharge from the nozzles 95% of the agent mass (at 70 °F (21 °C)) necessary to achieve the minimum design concentration" [1].

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While liquid run-out does not strictly represent a 95% mass discharge and the actual portion of the initial mass discharged by the liquid run-out time varied with system parameters, it was generally considered a good estimate for discharge time verification. For FM-200, nozzle liquid run-out typically represents between approximately 93 and 98% of the initial mass depending upon such system parameters as the initial fill density and network pipe volume. For Halon 1301, nozzle liquid run-out represents between approximately 86 and 95% depending upon the same parameters. With FE-13, due to its high vapor pressure and because it **is** not superpressurized with nitrogen, nozzle liquid run-out represents between approximately 50 to 85% depending upon the same system parameters. Figure 1 also shows an example of an FE-13 pressure trace, where nozzle liquid run-out time is not as clearly evident as on the similar FM-200 pressure trace. This significantly wider and lower range of mass percentage at nozzle liquid run-out for FE-13 negates the use of this indicator for discharge time.

The strategy evolved to overcome these problems was to estimate the mass remaining in the discharge cylinder and the associated pipe network. This estimate was made by calculating the mean agent density in the discharge cylinder and applying that density to the volume of the entire discharge system. This methodology in practice yields a conservative estimate of the mass remaining in the network as the density in the cylinder will he greater than that anywhere downstream in the piping. The one exception to this assumption is during the time period when the cylinder has run-out of liquid and there is still liquid remaining in the pipe network. Using this methodology to determine the discharge time, therefore, contains the implicit assumption that the discharge time is determined after nozzle liquid run-out. For FE-13, testing results have shown this is a reasonable assumption.

It was initially attempted to calculate the density in the agent cylinder by directly weighing the mass of the cylinder over the course of the discharge. This approach is easier than measuring the mass discharged from a nozzle because of the availability of flexible connections that will not adversely affect the flow of the agent, and because it is a single measurement rather than a multiple measurement with a lesser variation in measurement range, In the end, this method was discarded due to the piping restrictions it imposed upon system layouts. Paramount among these piping restrictions is that the flexible hose must he kept in a horizontal configuration and have just the right amount of tension, so that neither the thrust of the agent nor the swelling of the hose has a vertical component to interfere with the weight measurement.

The evolved method utilizes a measured cylinder pressure, an implied temperature. and an equation of state to determine the density of the agent remaining in the cylinder. The Martin-Hou equation of state was used in this method as it had already been fitted to the thermodynamic properties of FE-13 and used by E.I. du Pont de Nemours and Company to correlate these properties in their technical literature. The Martin-Hou equation of state has the following form and constants for **FE-13:**

$$P = \frac{RT}{(V-b)} + \sum_{i=2}^{5} \left[\frac{A_i + B_i + C_i \exp(-kT/T_c)}{(V-b)^i} \right] \qquad (1)$$

where:

P = pressure *[psia]*
T = temperature *[°R]*

V = specific volume $[ft^3/lb]$
R = ideal gas constant with a value of 0.1533 $[(psia\ ft^3)/(lb\ °R)]$
T_c = critical temperature with a value of 583 $[°R]$
b = 1.25E-3
k = 5.5

A, B. and C are given in Table 1.

TABLE 1. CONSTANTS USED IN EQUATION 1.

	2	3	4	5
A	-4.619499	-1.2475E-2	2.068042E-3	-3.868546E-5
B	3.472778E-3	7.733388E-5	-3.684238E-6	6.455643E-8
C	-159.7752	5.941212	0	-1.394214E-4

The temperature used in the estimation was not measured directly due to errors caused by the slow response time of the thermocouples when applied to slow moving gases (inside the cylinder). The boiling point temperature for the measured pressure was used instead. This temperature was determined using the following correlation:

$$LogP_{sat} = A + \frac{B}{T} + CLogT + DT + ET^2 + FT^3 \qquad (2)$$

where:

A = 328.9085
B = -1952.769
C = -144.5142
D = 0.242115
E = -2.128067E-4
F = 9.434955E-4
P_{sat} = saturation or vapor pressure $[psia]$
T = temperature $[°R]$

DISCHARGE TESTING REQUIREMENTS AND TECHNIQUES

The final critical parameter in any given discharge Lest, as mentioned above. is the measurement of the mass of agent discharged from each nozzle and comparison to the calculated values. Typically, and as is described in the newly adopted UL2166 standard, small enclosures arc constructed for each nozzle. the agent is collected in the enclosure and the concentration measured to calculate the agent mass.

While this methodology is universally accepted, it can be costly, and is riddled with potential sources of error. As an alternative to this method, Kidde-Fenwal has developed a patented technology utilizing polyethylene “lay flat tubing,” 2.6 ft in diameter, to “catch” the agent as it is dispersed from the nozzles. This methodology has been very successful for FM-200 testing, and is detailed by Senecal and Prescott [2].

To adapt this method to FE-13 testing, several improvements were adopted.

(a) In our traditional methodology, a load cell was used for the weighing of the polyethylene bag (Figure 2). However, the use of the load cell, in original testing procedures, was found to be burdensome and the data often drifted in reading, leading to questionable accuracy. **A** sample of the weight data from this configuration is also shown in Figure 2. To solve this problem. several components of known accuracy and stability were instituted into one measurement system. Figure 3 shows the components as used in the FE-I 3 engineered discharge testing.

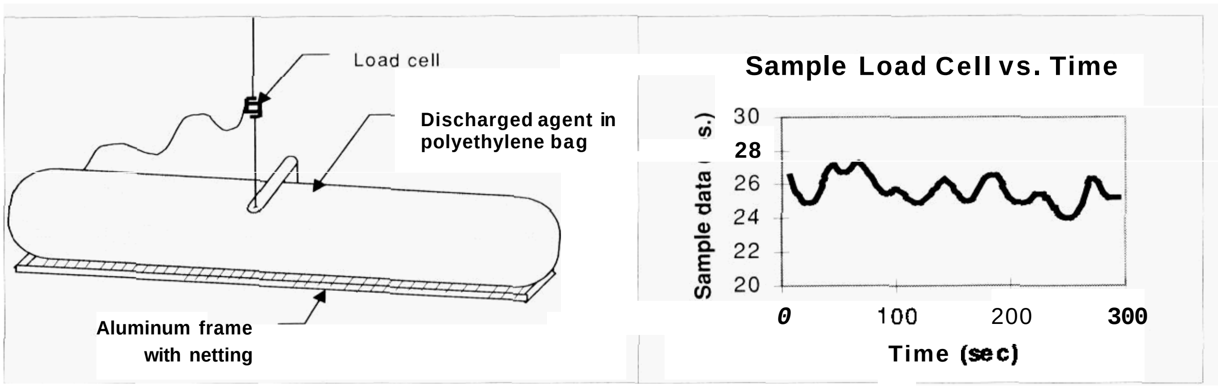

Figure 2. Load cell weighing, sketch, and data.

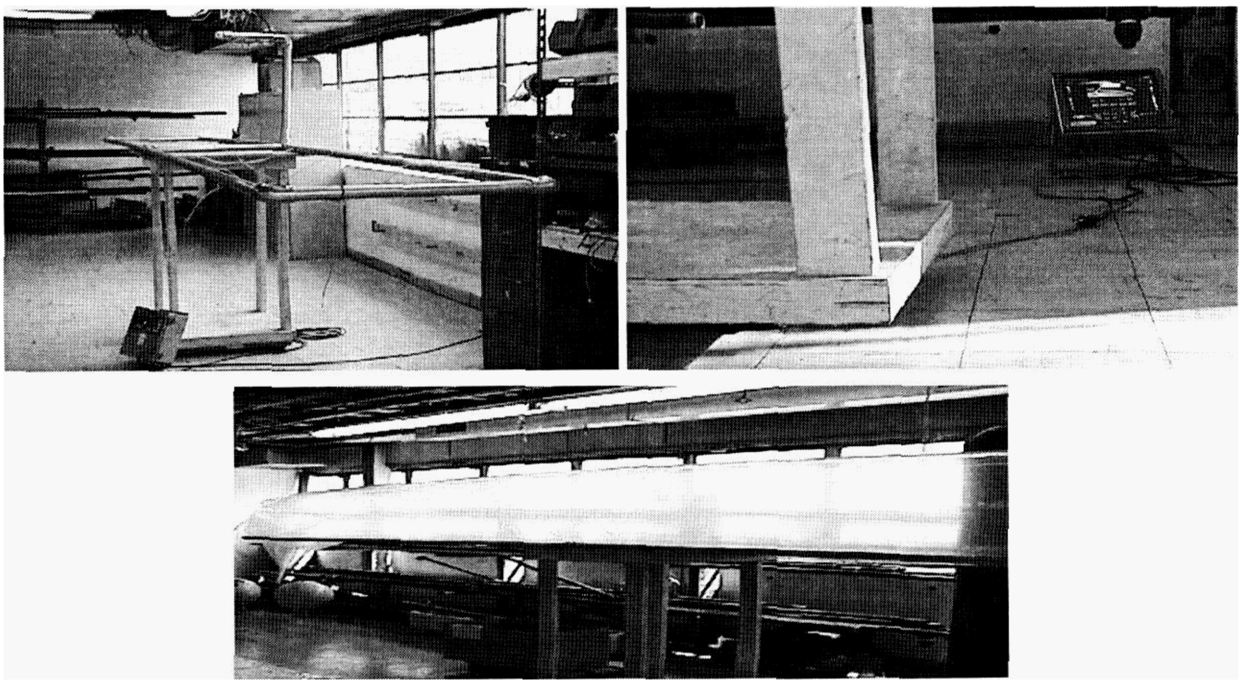

Figure 3. Scale weighing system.

(b) The measured value of the collection bag mass, as demonstrated in Figure 2, involves a buoyancy conversion through the ratio of molecular weight of air and the molecular weight of the agent.

$$W = (W_{full\,bag} - W_{empty\,bag}) \cdot \left(\frac{\quad}{\quad} \right)$$

However, the nozzle diffusers installed just downstrcam of the nozzles collect a volume of agent, which must be accounted for when determining the mass discharged from the nozzle. After considerable testing, the temperature of the agent inside the diffuser can be estimated. The density of tlie vapor is determined from this temperature, and the agent mass inside the diffuser volume is accounted for. It is noteworthy to include, with these buoyancy and duct volume corrections, that the agent recovery percentage averages approximately 99.5%. That is, 99.5% of the agent placed in the container is accounted for after discharge. Discrepancies are normalized. to ensure the intended agent quantity is used for comparison with the flow calculation predictions.

(c) As mentioned previously (CALCULATION OF DISCHARGE TIME). the nozzle forces and thrust of the discharging liquid agent present a formidable challenge in the measurement and collection of discharging fire suppression agents. Typically, a deflector is used to deflect the agent into the collection bags. Due primarily to the significantly higher system prcssurc than FM-200, the discharge of FE-13 requires something more rigid and structurally sound to ensure the collection bags are not damaged during discharge. Figure 4 shows the design of a unique diffuser constructed of galvanized ventilation duct. as well as a piping union and permanent pipe plug affixed to the nozzle drop. With this design. the agent liquid velocity is sufficiently reduced in order to collect the agcnt in the polyethylene bags, while not inhibiting the critical flow geometry and behavior at the nozzle orifice.

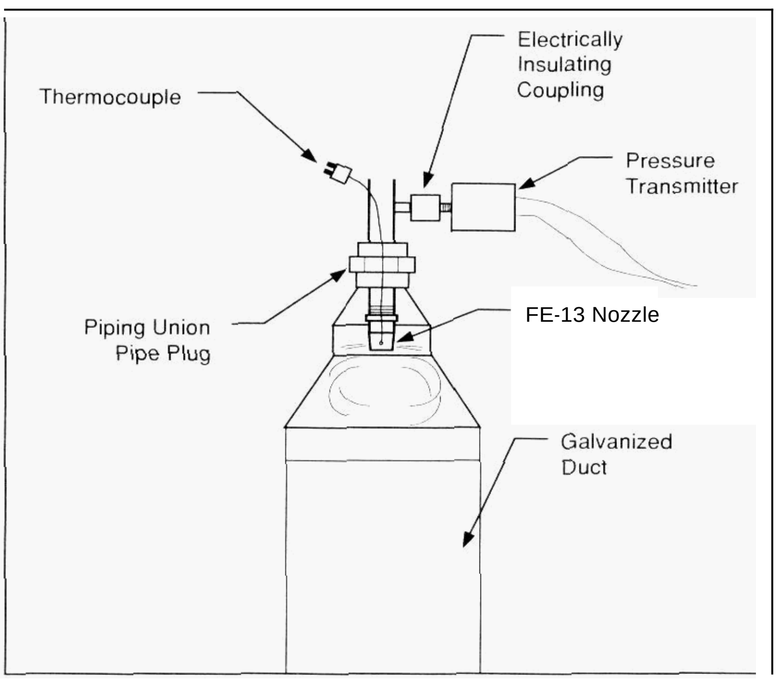

Figure 4. Nozzle instrumentation and diffusion arrangement.

(d) UL 1058 is the standard most typically used in the testing and verification of a clean agent, engineered fire suppression system [3]. **As** of 31 Mar. 1999, this document has been superseded by UL 2166 [4]. Section 33, *Verification of Flow Calculation Method Test* of UL 1058, dated 31 August 1995, lists a variety of flow parameters to be varied during the test program. **A** partial listing of these items was given previously (see INTRODUCTION). However, one item that is notably missing from the list given in UL 1058, Section 33.2, is the testing of the system with the maximum elevation change allowable. During the FE-13 engineered system development testing, listing requirements were imposed to test at this maximum elevation change, 25 ft for the Kidde-Fenwal FE-13 system. To facilitate this requirement, testing was performed in a warehouse environment with nozzles (complete with diffusers and agent collection bags) installed at a 25-foot height from the cylinder outlet. We believe this testing to be the first halon replacement flow verification testing performed at an elevation change of 25 ft.

(e) Halon 1301 and FM-200 systems are both typically superpressurized with nitrogen, to a pressure of 360 psig (or 600 psig in the case of some Halon 1301 systems). **As** with any compressed fluid, the pressure in the container will vary with temperature. In the case of a temperature range of 60 - 80 °F the pressure change in the cylinder (for 360 psig charge) is approximately ± 4% for FM-200 and ± 9% for Halon 1301. In the case of FE-13, which is not superpressurized with nitrogen, the vapor pressure over the same temperature range yields approximately ± 18% variation. With this knowledge of slightly larger pressure variation, the question was raised as to the validity of the engineered software predictions over the desired allowable storage temperature range for a multi-hazard system, 70 ± 10 °F. Variations in a critical initial condition, such as container pressure, were perceived possibly to produce inaccurate software predictions of nozzle mass. As a result, several tests were required to be performed with cylinder starting conditions of 60 and 80 °F. The pass/fail criteria established for these tests was only a verification that the nozzle mass prediction did not deviate from the permitted +10 and -5%. In each of the 4 cases tested, (2 unique piping systems, each tested with an initial container storage temperature of 60 and 80 °F) the nozzle mass prediction did not deviate from the +10 and -5% requirement. More specifically, the software predictions of nozzle mass, calculated assuming a container storage temperature of 70 °F (which is a constant and may not be varied by the software user), agreed with the experimentally measured values of tests with container storage temperatures of 60 and 80 °F, within the allotted tolerance. It is important to conclude, that if the FE-13 container storage temperature fluctuates between 60 and 80 °F, the mass prediction accuracy of the engineered software, is not compromised. We believe this testing to be the first successful engineered verification testing of a halon replacement agent, at any temperature extreme.

CONCLUSION

Anyone familiar with the development of a clean agent, engineered fire suppression system, understands the complex nature and challenging requirements of third-party verification. In the case of a halocarbon agent that has never been tested under these conditions, increased scrutiny of the agent physical properties and inexperience with the behavior of the agent during discharge often necessitate additional testing requirements and testing methodologies that have never been adopted. For FE-13, particular challenges existed in the measurement of discharge time and in various testing requirements and methodologies. This discussion has outlined the development of a conservative method to determine the discharge time of an FE-13 system. This method was agreed to conform to the essence of the UL 1058 and NFPA 2001 standards. Additionally, this report has described how the FE-13 system has undergone an abundance of qualification testing that would not typically be required, under the two aforementioned fire protection standards. In each case, testing was successfully completed to meet the requirements of third-party verification. Finally. innovative testing techniques have been shown in this report. which paved the way for the successful testing and ultimately product listing.

As the development of new agents. and systems continues. both fire suppression systems manufacturers and listing/approval organizations must continue to work together to ensure that the end product delivered *is* not overburdened with testing requirements, but provides the greatest level of fire protection possible.

REFERENCES

1. *NFPA 2001: Standard on Clean Agent Fire Extinguishing Systems, 1994 Edition.* National Fire Protection Association, Quincy. MA.
2. Senecal. Joseph A. and Prescott. Robert C., "FM-200 Suppression Systems: A Conservative Discharge Test Method and In-Room Pressure Variance Upon Discharge." *Proceedings*, Halon Options Technical Working Conference Proceedings. Albuquerque, NM, pp. 159-170, 1995.
3. *UL 1058: UL Standard for Safety for Halogenated Agent Extinguishing System Units, Third Edition.* Aug. 31, 1995. Underwriters Laboratories, Inc.. Northbrook, IL.
4. *UL 2166: UL Standard for Safety for Halocarbon Clean Agent Extinguishing System Units. First Edition.* Mar. 31, 1999. Underwriters Laboratories, Inc.. Northbrook, IL.