PRESSURE DYNAMICS OF CLEAN AGENT DISCHARGES

Mark L. Robin, Hughes Associates, Inc., West Lafayette, IN
(Ph: 765-583-0718; fax: 765-583-2066; mrobin@haifire.com),

Eric W. Forssell, Hughes Associates, Inc., Baltimore, MD
(Ph: 410-737-8677; Fax: 410-737-8688; ericf@haifire.com), and

Vimal Sharma, Great Lakes Chemical Corporation, West Lafayette, IN
(Ph: 765-497-6100; vsharma@glcc.com).

ABSTRACT

Despite the long held agreement that a knowledge of enclosure integrity is an essential element in the design of fire protection systems, relatively little information is available concerning the development of enclosure pressure during the discharge of gaseous agents.

Room pressure development during clean agent discharges is dependent upon several system- and enclosure-related factors. A major factor influencing the development of room pressure is the nature of the clean agent. The discharge of inert gas agents is characterized by a rapid buildup of pressure to a maximum, followed by a relatively slow decay in pressure with time. The discharge of halocarbon-based agents on the other hand, is characterized by an initial, relatively rapid negative pressure pulse, due to initial cooling of the enclosure and its contents, followed by a relatively rapid positive pressure pulse. Additional factors influencing the development of room pressure during a clean agent discharge include the enclosure construction, the enclosure integrity (leakage area, hold time), the fire size per enclosure volume ratio, and the agent flow rate.

Details of the effects of the above factors on room pressure development for both inert gas and halocarbon-based systems will be reviewed, along with data relating enclosure pressurization to enclosure integrity. Approaches to the evaluation of enclosure strengths for various construction types will be discussed, and recently developed methodologies for the prediction of the pressure dynamics of clean agent discharges will also be reviewed.

PRESSURE DYNAMICS: OBSERVATIONS

Room pressure development during clean agent discharges is dependent upon several system- and enclosure-related factors. A major factor influencing the development of room pressure is the nature of the clean agent. Figure 1 shows the variation of the room pressure with time for the discharge of Inergen®, an inert gas type clean agent. The discharge of an inert gas agent is characterized by a rapid buildup of pressure to a maximum, followed by a relatively slow decay in pressure with time. Figure 2 shows the variation of the room pressure with time for the discharge of FM-200®, a halocarbon type clean agent. For halocarbon-based clean agents, an initial negative pressure event occurs: the agent undergoes a phase change from liquid to vapor

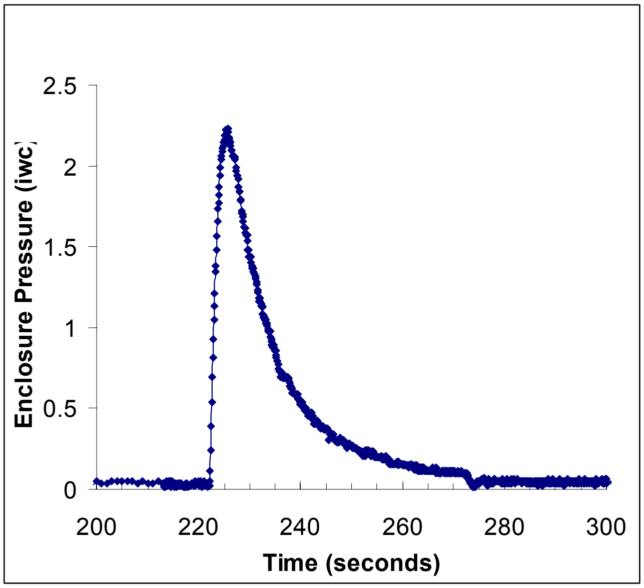


Figure 1. Development of Room Pressure During the Discharge of 30.9% v/v Inergen®

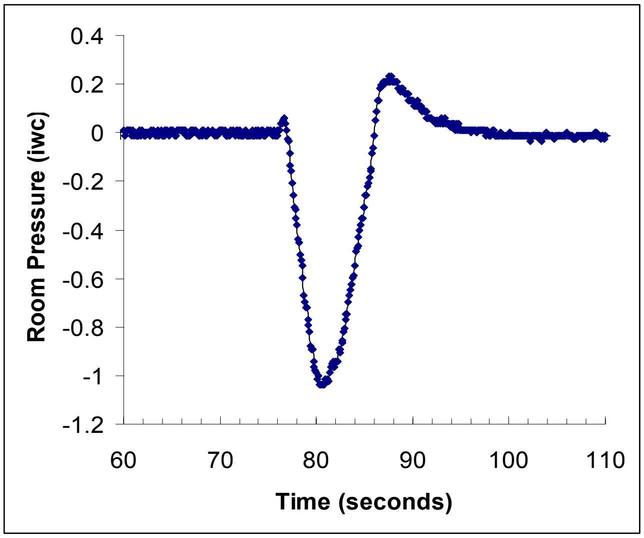


Figure 2. Development of Room Pressure During the Discharge of 6.1% v/v FM-200®

at the nozzle, which results in the absorption of heat from enclosure air and a decrease in the room pressure to below the ambient pressure. The negative pressure event is followed by a positive pressure event during which heat transfer occurs from the enclosure and its contents to the cooled air and expansion of the agent results in an increase in room pressure to above the ambient pressure. Hence, the discharge of halocarbon-based clean agents is characterized by an initial, relatively rapid negative pressure pulse, due to initial cooling of the enclosure and its contents, followed by a relatively rapid positive pressure pulse.

Previous studies [1-3] of the pressure dynamics of halocarbon agent discharges have shown that the magnitude of the enclosure pressures developed is dependent upon several factors, including:

- Agent properties
- Agent concentration
- Discharge time
- Enclosure leakage area
- Enclosure construction
- Fire size

As discussed above, the pressure dynamics of inert gas agent discharges differ significantly from the pressure dynamics of halocarbon-based agent discharges. The thermodynamic properties of a halocarbon-based agent will determine the extent of heat transfer occurring during agent discharge, and hence the pressure dynamics of different halocarbon-based agents will be different. Testing with FM-200® indicated a dependence of the enclosure pressure on the agent concentration. Figure 3 shows the maximum and minimum enclosure pressures measured during the cold discharge of FM-200® in an 85 m^3 enclosure constructed from 2x4 wood studs and gypsum wallboard. As can be seen from Figure 3, as the agent concentration increases, the magnitude of the positive and negative pressure pulses also increases.

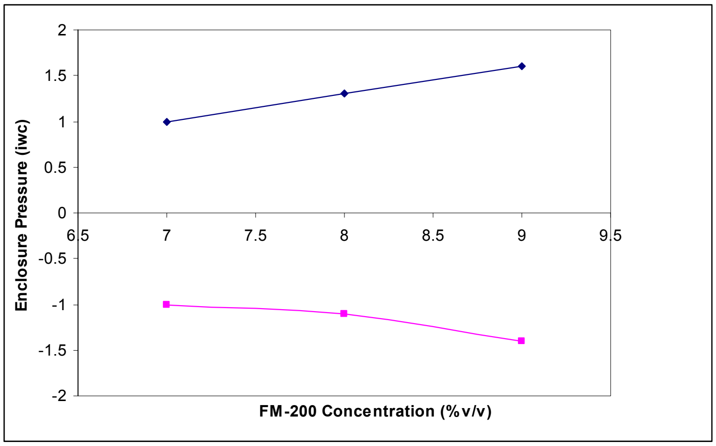


Figure 3. Effect of Concentration on Enclosure Pressure.
FM-200®, 10 s discharge; leakage area 35 sq. in.

The discharge time was found to have little effect on the enclosure pressure [1], for discharge times ranging between 6 and 10 seconds. For example, Figure 4 shows the effect of the discharge time on the enclosure pressure for the discharge of 8% v/v FM-200® on a 445 mm heptane pan fire. The effect of the leakage area on the enclosure pressure is as expected: as the leakage area is increased, the magnitude of the enclosure pressures decreases, as seen in Figure 5.

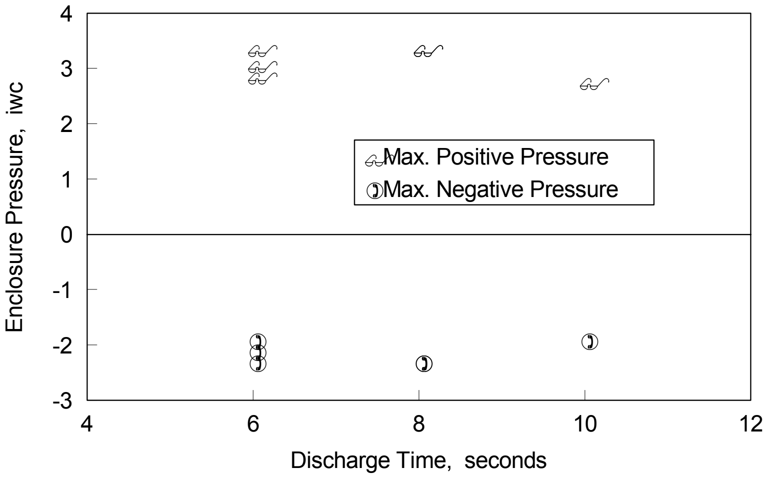


**Figure 4. Effect of Discharge Time on Enclosure Pressure.
8 % v/v FM-200®; 445 mm heptane pan fire.**

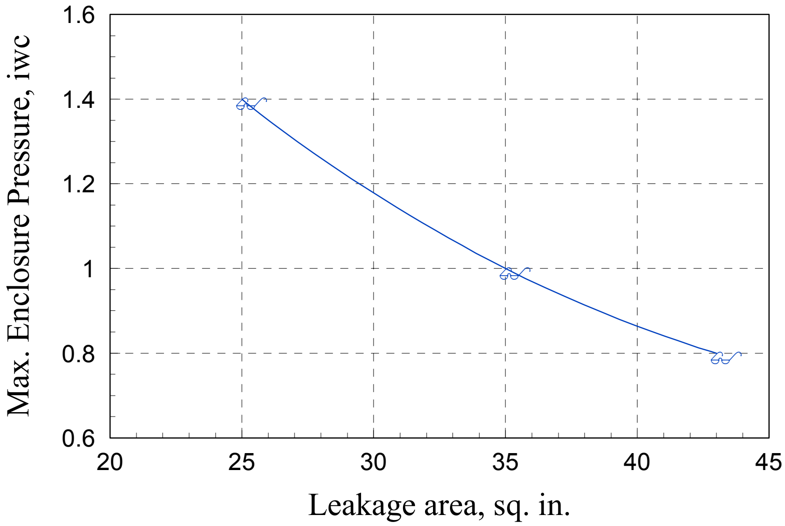
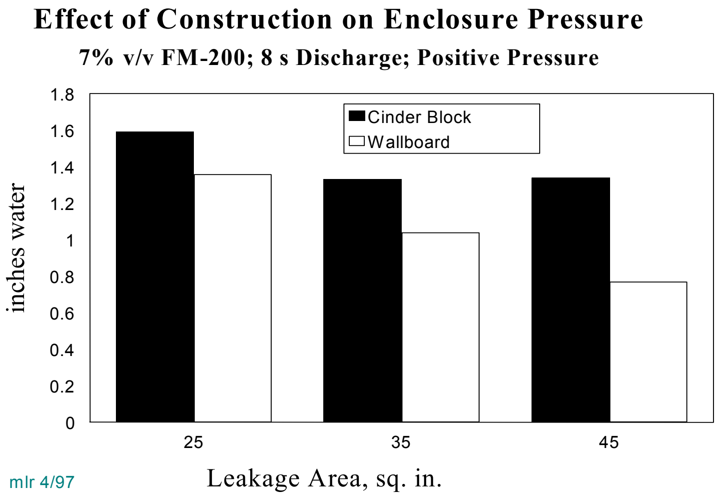


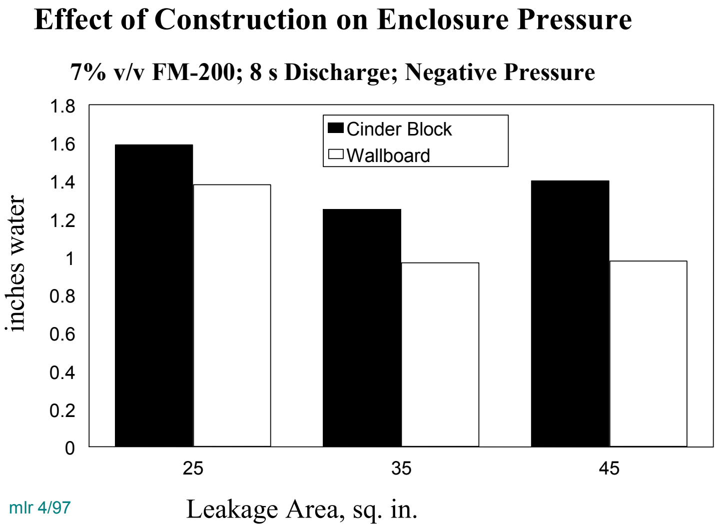
**Figure 5. Effect of Leakage Area on Enclosure Pressure
7% FM-200®; 8 second discharge**

The construction of the enclosure has been observed to affect the magnitude of the enclosure pressures developed, as seen in Figures 6 and 7. The magnitude of enclosure pressure was observed to be larger in an enclosure constructed of cinder block compared to a similar structure constructed from gypsum wallboard and 2x4 studs. This was attributed to the greater flexibility of the wallboard construction, which afforded a dampening of the pressure pulses.



mlr 4/97

Figure 6. Effect of Construction on Maximum Positive Enclosure Pressure



mlr 4/97

Figure 7. Effect of Construction on Maximum Negative Enclosure Pressure

The fire size has been observed to have a large influence on the enclosure pressure as shown in Figures 8 and 9. An increase in fire size results in an increase in the magnitude of both the positive and negative pressure pulses associated with the discharge of a halocarbon-based agent.

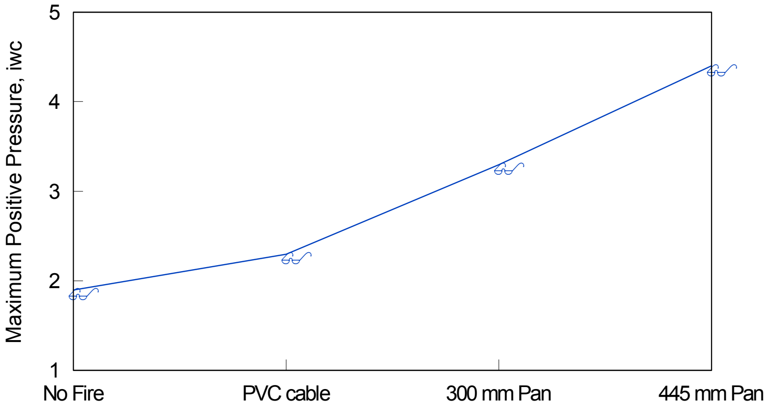


Figure 8. Effect of Fire Size on Maximum Positive Enclosure Pressure; 7 % FM-200®

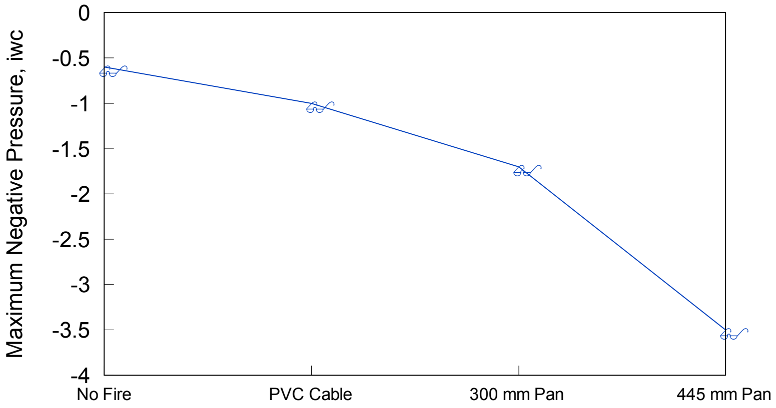


Figure 9. Effect of Fire Size on Maximum Negative Enclosure Pressure; 7% FM-200®

PRESSURE DYNAMICS: MODELING

The inert gas-type clean agents are all based on ideal gases. Calculation of enclosure pressures can be accomplished by assuming ideal gas behavior, and venting information is available from the agent manufacturers to allow for the calculation of the vent sizes required to ensure enclosure pressurization does not occur. The halocarbon-based clean agents, however, do not behave as ideal gases, and the prediction of enclosure pressures developed upon their discharge is a much more difficult challenge than in the case of the inert gas clean agents.

A model for use in predicting the enclosure pressures developed during the discharge of a clean fire suppression agent, either inert gas or halocarbon-type, into an enclosed space had been previously developed by Hughes Associates, Inc. [4]. The model utilizes a mass balance, an energy balance and the Soave modification of the Redlich- Kwong equation of state. This model also utilizes the Hughes Associates, Inc (HAI) Clean Agent flow model to provide the required flow rate and thermodynamic state of the agent and super-pressurizing nitrogen as they enter the enclosure. The model assumes instantaneous mixing throughout the enclosure and complete vaporization of the agent.

In comparison with experimental data, this early model has a tendency to accurately predict pressures for small enclosures (on the order of 400 ft^3), but over-predicts the negative pressure pulse and under-predicts the positive pressure pulse in larger enclosures (on the order of 3,500 ft^3). This was believed to be due to the neglecting of heat transfer to the vaporizing liquid agent as it comes into contact with the ceiling near the nozzle location.

In order to account for this heat uptake, a sub-model was added to the program. The portion of the ceiling and the amount of the agent liquid that was involved in this heat transfer was estimated based upon the liquid flow rate and pressure at the nozzle. A lumped heat capacity-based energy balance was applied to the involved section of the ceiling to account for the reduction in heat transfer over time due to the temperature reduction of the ceiling section. With the addition of the sub-model, pressures in the larger enclosures were accurately predicted. However, for the smaller enclosures, the sub-model had to be defeated/removed to regain accurate predictions.

In order to obtain accurate predictions for a wide range of enclosure sizes, a set of experiments involving the discharge of FM-200® were designed to allow for the development of an improved correlation for the portion of the ceiling and the amount of agent liquid involved in this enhanced heat transfer process. The experimental program examined the effect of the following variables on the enclosure pressure dynamics:

- Nozzle to ceiling distance
- Nozzle to wall distance
- Average nozzle pressure
- Liquid flow rate

Based upon the experimental results, a correlation was developed relating the portion of the ceiling and the amount of the agent liquid involved in heat transfer to the liquid flow rate and pressure at the nozzle, and the distance between the nozzle and the walls of the enclosure.

Table 1 compares the peak pressure values predicted by the enhanced model with experimentally measured values. For fill densities above approximately 35 lb/ft^3, the enhanced model predicts the maximum and minimum enclosure pressures to within approximately 0.5 iwc of the experimentally observed values. Figure 10 compares the predicted enclosure pressure with the experimentally observed enclosure pressure for the discharge of 8% v/v FM-200® in a 3355 ft^3 (95 m^3) enclosure employing gypsum wallboard and 2x4 stud construction, and characterized by a leakage area of 43 in^2.

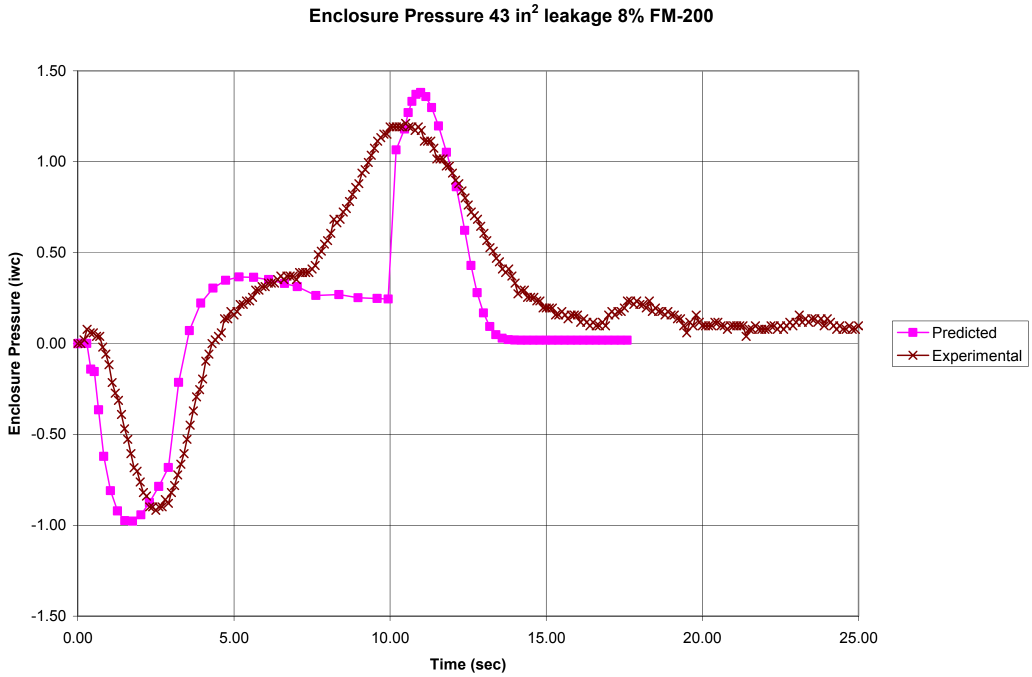


Figure 10. Predicted and Experimental Enclosure Pressures

GEP9; 8% FM-200®; 8 s discharge; wallboard/2x4 construction

Table 1. Prediction of Enclosure Pressures. FM-200®

TestName		Enclosure Volume ft^3	Enclosure Height ft	Leakage Area ft^2	Conc. % v/v	Predicted Max. Enclosure P iwc	Experimental Max. Enclosure P iwc	Max. Enclosure Pressure Pred - Exp iwc	Predicted Min. Enclosure P iwc	Experimental Min. Enclosure P iwc	Min. Enclosure Pressure Pred - Exp iwc
GS50	UL2166 pl. sheets in 8'x8'x10'	517	9.8	0.10	4.9	0.20	0.55	-0.35	-0.61	-1.15	0.54
GS55	UL2166 pl. sheets in 8'x8'x10'	517	9.8	0.10	5.4	0.16	0.46	-0.30	-0.66	-1.18	0.52
GS58	UL2166 pl. sheets in 8'x8'x10'	517	9.8	0.10	5.7	0.15	0.32	-0.17	-0.72	-0.95	0.23
GS65	UL2166 pl. sheets in 8'x8'x10'	517	9.8	0.10	6.4	0.18	0.48	-0.30	-0.84	-1.01	0.17
GS70	UL2166 pl. sheets in 8'x8'x10'	517	9.8	0.10	6.9	0.20	0.51	-0.32	-0.88	-1.04	0.16
GLEP7-35	EIDO Pressure Tests	3011	9.8	0.24	7.0	1.42	1.00	0.42	-1.26	-1.00	-0.26
GLEP7-43	EIDO Pressure Tests	3011	9.8	0.30	7.0	1.13	0.80	0.33	-0.97	-1.00	0.03
GLEP8-35	EIDO Pressure Tests	3011	9.8	0.24	8.1	1.72	1.30	0.42	-1.26	-1.10	-0.16
GLEP8-43	EIDO Pressure Tests	3011	9.8	0.30	8.1	1.38	1.20	0.18	-0.98	-0.90	-0.08
GLEP9-35	EIDO Pressure Tests	3011	9.8	0.24	9.2	1.80	1.60	0.20	-1.23	-1.40	0.17
GLEP9-43	EIDO Pressure Tests	3011	9.8	0.30	9.2	1.43	1.30	0.13	-0.97	-1.20	0.23
Hygood-3	IMO telltales	17640	16.4	1.80	7.4	1.21	1.21	0.00	-0.61	-0.60	-0.01
KF-180	IMO telltales	17640	16.4	1.80	6.9	0.46	0.80	-0.35	-0.24	-0.40	0.17
G12EP6	HAI Fall 2004	3591	12.0	0.31	5.9	0.40	0.21	0.19	-0.94	-1.23	0.29
G12EP8	HAI Fall 2004	3591	12.0	0.31	5.9	0.40	0.24	0.16	-0.94	-1.14	0.20
G12EP10	HAI Fall 2004	3591	12.0	0.31	5.9	0.40	0.19	0.21	-0.94	-1.07	0.13
GP16F9	HAI Fall 2004	3505	16.0	0.32	6.0	0.34	0.29	0.05	-0.90	-0.60	-0.30
GP16F10	HAI Fall 2004	3505	16.0	0.32	6.0	0.34	0.27	0.07	-0.90	-0.65	-0.25
GP16F11	HAI Fall 2004	3505	16.0	0.32	6.0	0.34	0.31	0.03	-0.90	-0.60	-0.30
G12EP11	HAI Fall 2004	1344	12.0	0.22	7.0	0.34	0.30	0.04	-1.03	-0.73	-0.30
G12EP12	HAI Fall 2004	1344	12.0	0.22	7.0	0.34	0.29	0.05	-1.03	-0.87	-0.16
G12EP13	HAI Fall 2004	1344	12.0	0.22	7.0	0.34	0.29	0.05	-1.03	-0.83	-0.20
concrete block											
GLEP7-41	GEP28					1.19	1.30	-0.11	-1.03	-1.40	0.37
GLEP8-41	GEP22					1.45	1.40	0.05	-1.04	-1.40	0.36
GEP27						1.45	1.29	0.16	-1.04	-1.58	0.54
GEP32						1.79	1.59	0.20	-1.65	-1.59	-0.06

ENCLOSURE STRENGTHS

The ability to accurately predict enclosure pressures resulting from clean agent discharges is of practical use only if the strength of the enclosure with respect to the maximum pressure it can accommodate is known. NFPA 12 (Carbon Dioxide) indicates, without explanation, that "light" construction can tolerate 25 psf of pressure and that "normal" construction can tolerate 50 psf. These values are apparently based on resistance to wind, and no definition of "light" or "normal" construction is provided in NFPA 12. A "rule of thumb" currently encountered in the field is a maximum pressure of 5 psf. This figure is apparently based on building code requirements for interior wall partitions subject to normal use.

A previous analysis by Harry, et. al. [2] of various structural elements indicated that the pressures developed during discharge of FM-200® are less than the yield strengths of structural members generally used in applications protected by FM-200® systems (interior, no-load bearing framing or partition studs).

Strength comparisons of concrete, masonry, and wood construction are available from construction material suppliers. Table 2, for example, shows the pressure limitations (based on wind loading) for several structural components [5]. In general, it can be observed that typical construction can tolerate at least 10 psf pressure. This is in agreement with observations made at Hughes Associates, Inc. during the discharge of clean agents in test enclosures employing 2x4 wood studs or steel studs and wallboard construction in enclosure of up to 16 feet in height: minor enclosure damage (i.e., the development of small cracks in the structure) do not occur until enclosure pressures exceed approximately 10 psf.

CONCLUSION

By accounting for the heat transfer to the vaporizing liquid agent as it comes into contact with the ceiling near the nozzle location, we have been able to refine our enclosure pressure model to allow for the accurate prediction of enclosure pressures developed during the discharge of the clean agent FM-200®. Maximum positive and negative enclosure pressures have been predicted to within 0.5 iwc for structures of various configuration. Combined with a knowledge of the strength of an enclosure with regard to pressurization, the use of the pressure model ensures the proper and safe design of FM-200® suppression systems.

Table 2. Strength of Walls. Exterior Wall, 10 Feet Tall [5]

Wall Type	Maximum Allowable Pressure (psf)
2x4 stud @ 16” OC	13
2x6 stud @ 16” OC	32
2x8 stud @ 16” OC	56
2x10 stud @ 16” OC	90
6” masonry reinforced	41
8” masonry reinforced	57
10” masonry reinforced	74
12’ masonry reinforced	91
4” concrete reinforced	59
6” concrete reinforced	89
8” concrete reinforced	120
4” concrete unreinforced	29
6” concrete unreinforced	66
8” concrete unreinforced	117

REFERENCES

1. Robin, M.L., “Investigation of the Pressure Dynamics of FM-200 System Discharges,” Proceedings of the 1997 Halon Options Technical Working Conference, May 6-8, 1997, Albuquerque, NM.

2. Harry, L.D., Meltzer, J.S., and Robin, M.L., “Development of Room Pressure in the Discharge of FM-200 Compared to the Strength of Various Structural Elements,” Proceedings of the 1997 Halon Options Technical Working Conference, May 6-8, 1997, Albuquerque, NM.

3. Senecal, J.A. and Prescott, R.C., “FM-200 Suppression Systems: A Conservative Discharge Test Method and IN-Room Pressure Variance Upon Discharge,” Proceedings of the 1997 Halon Options Technical Working Conference, Mat 6-8, 1997, Albuquerque, NM.

4. DiNenno, P.J. and Forssell, E.W., “Evaluation of Alternative Agents for Use in Total Flooding Fire Protection Systems,” NASA SBIR Phase II Final Report, NASA, Kennedy Space Center, FL, 1994.
5. Technical Bulletin ICF No. 7004, “Concrete, Masonry, Wood Wall Strength Comparisons, Feb. 1995 (revised March 1999), AFM Corporation.