Clean Agent Enclosure Design for NFP

By Colin Genge

The Clean Agent Discharge

Clean agent fire suppression systems are used in enclosures where a sprinkler system would cause damage to sensitive contents such as computer servers, paper files, or historical artifacts. Upon fire detection the compressed clean agent, which can be a halocarbon or an inert gas, is released into the enclosure causing a peak pressure of around 5 to 25 pounds per square foot to occur for a fraction of a second. The actual magnitude depends on total enclosure leakage area. Once the enclosure is totally flooded, the agent will begin to leak out at a rate that primarily depends upon leakage area in the lower part of the enclosure. The distribution of the remaining agent will either be constant throughout the enclosure due to continual mixing or will establish an interface with air above and agent below that descends over time as agent leaks out as shown in Figure 2. Until 1988, enclosures protected by clean agents used full discharge tests to determine the hold time, but since then door fans have been used to measure the leakage area which is then entered into formulae found in Annex C of NFPA 2001 to predict the hold time.

Under-prediction of Peak Pressure

It is common practice for peak pressure calculations to be done for inert agents but not for halocarbon agents and that is a big problem since they can produce as much peak pressure as inert agents. Peak Pressure varies over time depending on the ratio between the leakage rate and the volume of the enclosure (leak to volume ratio, or LVR). In a typical halocarbon agent discharge, as shown in Figure 3, the peak pressure increases with enclosure tightness since tightness determines the increasing hold times shown in the legend. Formulae for calculating peak pressure may be provided by agent manufacturers. Although peak pressure is referred to by the NFPA 2001 standard, the standard does not yet provide guidance on how it is to be calculated.

A five-year research project—carried out to provide a validated prediction model for peak pressure based on LVR and involving the author and many of the industry manufacturers (including Fike, 3M, Ansul, Kidde Fenwal, Chemetron, Retrotec)—has uncovered many important facts about clean agent discharge pressures and the peak

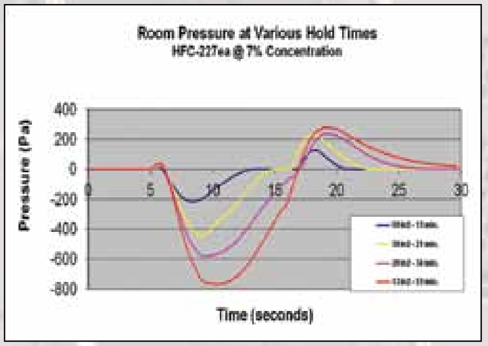

Figure 3: Typical halocarbon discharge showing peak pressure increasing with enclosure tightness (longer hold times).

pressure formulae previously used to predict pressure values during enclosure design and testing. These facts include:

1. Existing inert agent formulae *under*-predict peak pressure.
2. Under certain conditions, halocarbon agents can produce as much peak pressure as inert agents.
3. Peak pressures from halocarbons are extremely dependent upon humidity.

Results of the project were published in the Fire Suppression Systems Association (FSSA)

Figure 1: The clean agent expands, causing cooling which condenses moisture to form a fog.

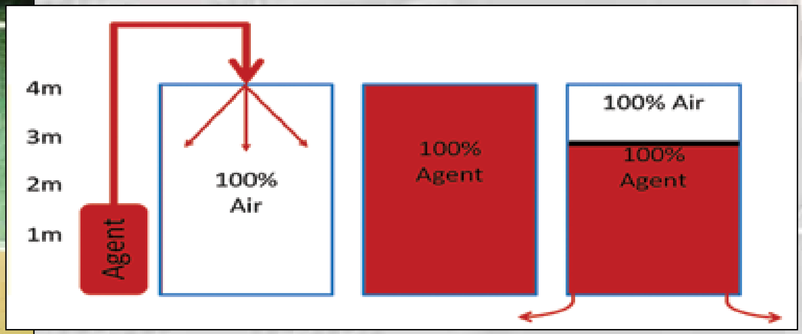

Figure 2: Graphical representation of the NFPA 2001, 2012 Edition, Annex C clean agent standard model for descending interface where 100 percent agent leaks out the bottom of the enclosure causing 100 percent air to be drawn in above the interface to replace the lost volume.

A 2001, 2012 Edition

Pressure Relief Vent (PRV) Area Guide.

Sufficient data was gathered to more accurately predict the peak pressure for all agents. Figure 4 shows the new curve (in white) developed for inert agent peak pressure versus LVR. Notice how the existing formulae (dashed lines) all *under*-predict the peak pressure expected at a given LVR over the typical peak pressure values from 250 to 500 Pa. Figure 5 shows the results of testing of peak pressures versus LVR for all tested inert agents in the research.

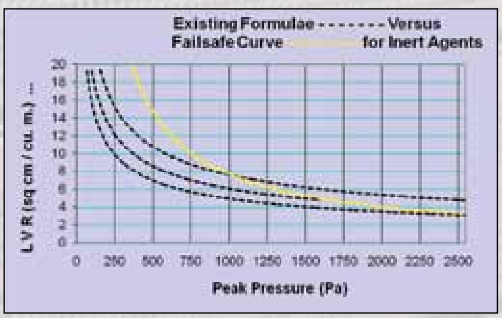

Figure 4: Peak pressure is a function of LVR (leakage to volume ratio). Existing formulae all under-predict at typical peak pressure values (250 to 500 Pa).

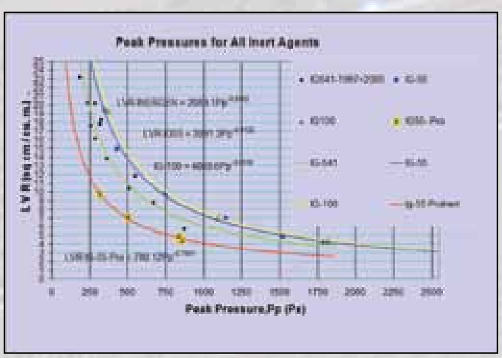

Figure 5: Peak Pressure curves for all tested inert agents.

A Second Leakage Area Must Now Be Measured

NFPA 2001, 2012 Edition, Section 5.1.2.2 (28) now requires a "specified enclosure pressure limit" which will, in turn, dictate the "minimum allowable leakage area" for the enclosure. This leakage area can be provided by unintentional enclosure leakage and/or the area of any dampers that will be open during the discharge period. The enclosure integrity procedure in Annex C has also been changed to require the measurement of two leakage area values, one used for the calculation of the hold time and another used for evaluating peak pressure during discharge. These values must be measured after the enclosure has been completed. The new leakage area measurement is now necessary to fulfill the new requirement in Section 5.1.2.2 (10) that states "an estimate of the maximum positive pressure and the maximum negative pressure" during the clean agent discharge must be made. Section 5.3.7 states "If the developed pressures present a threat to the structural strength of the enclosure, venting shall be provided to prevent excessive pressures." Clearly it would be extremely bad news to find out that a completed enclosure needed to have a pressure relief vent (PRV) installed a few days before occupancy, but fortunately the designer can run calculations in advance using the new peak pressure equations that have come out of the research project to determine whether or not a PRV is likely to be needed and alter the design using the tips presented later in this article.

It is no longer sufficient to simply specify a PRV of the correct size; its leakage rate must also be measured after installation to ensure the vent both opens at the correct pressure and has a large enough leakage path outdoors to prevent the peak pressure from exceeding the specified enclosure pressure limit. The 2008 edition requires this new second measurement which can be done using the same Annex C enclosure integrity procedure but with different set-up conditions. The same door fan equipment can often be used, but users may find they need higher fan output to test at 50 Pa instead of the previous 10 Pa and need to test with the PRVs open.

Optimizing Peak Pressure and Hold Time Performance

Clean agent discharges can produce damaging peak enclosure pressures that increase as total enclosure leakage area decreases. Simply providing a lot of enclosure leakage area to solve the peak pressure problem creates another problem because hold times decrease as the leakage area increases. One solution is to add a PRV that will provide increased leakage to reduce the peak enclosure pressure only during discharge; the enclosure can then be made tight to provide the specified hold time. Another solution is to carefully consider the design parameters that affect peak pressure and hold time so that both requirements are met without using PRVs. Even if this design effort still results in the need for PRVs, optimizing the enclosure will increase the level of fire protection and possibly allow the use of smaller PRVs since more passive protection will be built in.

Ironically, many inert agent protected enclosures have PRVs installed where they are *not needed* while other enclosures (protected by both inert and halocarbon agents) *need* PRVs but they are not installed. This situation can be resolved by using the new enclosure integrity evaluation procedure from Annex C of NFPA 2001 along with the new peak pressure formulae. Adding PRVs is costly, sometimes impossible, and often a source of unwanted risk since they may fail to open and could damage the enclosure.

Understanding the factors that affect the relationship between peak pressure and hold time will allow for designs without PRVs that easily pass both criteria. Invariably, a few simple changes to the enclosure will dramatically improve the suppression system's performance and also save the installer from having to resolve difficult design problems in a last-minute panic when the enclosure fails one or more of the acceptance criteria which typically occurs just prior to occupancy.

Selection of Specified Enclosure Pressure Limit

Formulae have been used for over a decade to predict peak pressures and to size PRVs for thousands of enclosures without damaging those enclosures. Since the five-year research project showed that the actual peak pressures exceeded those predicted by the previously used formulae by at least 100 percent, and many of those enclosures were discharge tested with inert agents, it is safe to say that a wide range of enclosures handled 500 Pa of peak pressure with ease. This has also been verified with the use of a high output fan to pressurize enclosures where we have noticed no effects at 500 Pa. We can therefore assume that a double-sided wall, securely fastened on the top and bottom, will handle 500 Pa and that 500 Pa can be used as a "specified enclosure pressure limit," which is the maximum pressure the enclosure can be subjected to without damage. If in doubt, test a wall section under the chosen specified enclosure pressure limit using a high-pressure door fan.

While thicker walls can take more pressure as shown in Figure 6, false ceilings can only take about 50 Pa so they must be protected from pressures higher than that with vented tiles. Ensure the false ceiling has at least 5 percent open area to prevent it from being dislodged as the discharge vents upwards.

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

Figure 6: Wall strength versus maximum allowable pressure in pounds per square foot for walls of different construction type.[2]

Selecting an Appropriate Hold Time

After a typical 10-second discharge for halocarbons or 60 seconds for inert agents, the hold time begins. Even though this time has almost always been specified as 10 minutes, there was no specific NFPA requirement until the 2008 edition when the words "a minimum period of 10 minutes or for a time period to allow for response by trained personnel" were added to section 5.6. Is 10 minutes always the correct hold time? The designer must consider what the "time period to allow for response by trained personnel" will actually be because much longer hold times are required for remote sites or those with heavy fuel loads while much shorter hold times can be considered for small enclosures that are manned 24/7. Reducing this hold time to 6 minutes for a small 1,250-cubic-foot enclosure and to 3 minutes for a 350-cubic-foot enclosure would solve one of the most costly and pernicious problems that installers face, where getting these enclosures tight enough to pass the 10-minute requirement becomes virtually impossible.

Enclosure Design Tips

The following design tips have the potential to do one or more of the following:

- reduce installation costs
- reduce risk of damage created by discharge pressures
- ease maintenance
- improve fire protection
- reduce the risk of smoke damage

The tips are meant to be considered during the design phase. The installed performance of the PRVs must be checked during installation to ensure they open at the correct pressure, in the correct direction, and that the free vent area of the entire vent path falls within the specification. A very different leakage test, with PRVs closed, is performed to ensure adequate retention time.

1. **Specify sealing of the walls to the upper slab.** Extending walls to the upper slab and sealing them airtight is the only defense against fire and smoke entering from outside the enclosure. Refer to C.1.2.1 (2) in NFPA 2001 which states "…enclosures absent of any containing barriers above the false ceiling, are not within the scope of Annex C" meaning the enclosure will be difficult to test and verify.
2. **Place nozzles to flood the entire enclosure with agent.** The higher the initially flooded height, the leakier the enclosure can be, producing less peak pressure but yielding longer hold times. Typically, the small savings generated by flooding only to the bottom of a false ceiling are more than offset by the increased air sealing costs needed to ensure adequate hold time and may also force the inclusion of PRVs more often. If a false ceiling is needed, specify nozzles above the ceiling; that's how virtually all systems are designed in Europe.
3. **Use an automatic door closing system.** Doors often get wedged or

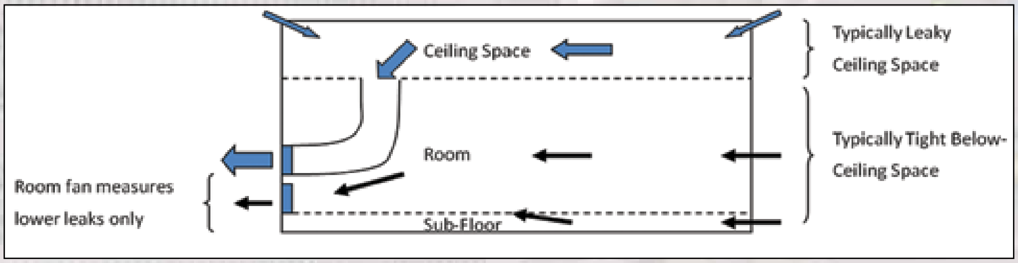

Figure 7: One door fan depressurizes the room while the second depressurizes above the ceiling so the pressure across the ceiling is zero, allowing the lower fan to measure the room leaks separate from above ceiling leaks.

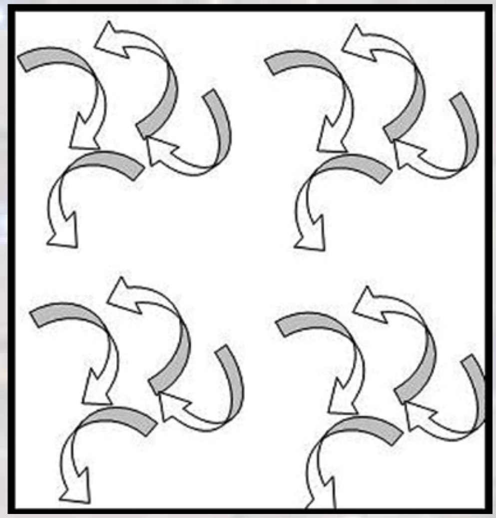

Figure 8: As agent is lost, air continually mixes with the agent to provide the same concentration everywhere in the enclosure.

propped open when the enclosure is in use. This practice impairs the clean agent system's ability to put the fire out. A better solution is an automatic door release mechanism that will close the doors whenever the first alarm sounds. Choose a mechanism that will close the door when it is de-energized so it is fail-safe.

4. **If a false ceiling is specified, require air sealing of lower leaks first until the specified hold time is reached and then seal leaks above the false ceiling up to the peak pressure limit.** The air leakage determination will require measuring upper and lower leaks separately as described in section C.2.7.2 and shown in Figure 7.
5. **Increase the initial concentration of agent an additional 15 percent over design concentration if continual mixing will occur, to ensure a long enough hold time.** If air handlers continue to run during the hold time, then continual mixing is certain but even equipment cooling fans or thermal effects can be sufficient to cause continual mixing. Increasing the gap between the initial and final concentration in the continual mixing case has the same effect as making the room taller in the descending interface case. For non-mixing cases, the agent is allowed to drain out until it hits the protected equipment which is typically at 60 to 75 percent of the enclosure height allowing 40 to 25 percent of the agent, respectively, to run out before the equipment is no longer protected. If additional agent were not added, only 15 percent of the agent would have to be lost before the equipment loses its protection, since the standard requires that the final concentration at the end of the hold time at the top of the protected equipment be not less than 85 percent of the design concentration. The latest version of the NFPA 2001 standard uses an integration formula that increases the hold time prediction somewhat, but it is still extremely important to add this additional agent otherwise the enclosure will fail the hold time after only 15 percent of the total weight of agent is lost.
6. **If no mixing will occur, keep the height of the protected equipment to a minimum.** If the equipment height exceeds 75 percent of enclosure height, continual mixing may be the only way to ensure a reasonable retention time.

Pressure Relief Vent (PRV) Tips

If PRVs must be installed, there are several guidelines to follow to optimize their performance:

- Install vents as high as possible so that the lighter air, not the denser agent, is vented.
- Vents should open at pressures no lower than 50 Pa to ensure they don't open unintentionally under normal HVAC pressures and no higher than 100 Pa so the pressure is vented early enough to prevent it from building up.
- Ensure the correct direction for venting with the PRV is specified. Inert agent discharges always create positive pressures and therefore must be vented out of the enclosure, but halocarbons may create positive and/or negative pressures, creating a need to be vented in either direction or both depending on the agent and the humidity.
- All PRVs should be inspected annually to confirm they will open according to their specifications and to verify that the vent path to the outdoors has not been accidently restricted which is quite common as evidenced by the sign shown in Figure 9.

Figure 9: The sign says "DO NOT OBSTRUCT" because it is very likely the vent path will be obstructed, thus the vent path must be checked regularly.

Peak Pressure Evaluation Tips

PRVs that are designed to open at a certain pressure must be tested prior to and/or after installation to verify they open at the prescribed pressure. 125 Pa is the pressure generally used to test PRVs because it is

AGENT	CONCENTRATION	LEAKAGE AREA	MIN. HEIGHT	OLD NFPA HOLD TIME | PEAK PRESSURE		NEW NFPA HOLD TIME | PEAK PRESSURE	
				ALL FAIL		ALL PASS	
DuPont™ FM-200®	7%	29 sq in	8.5 ft	9.3 min.	382 Pa	10.4 min.	247 Pa
3M™ Novec™ 1230	4.5%	43 sq in	7.5 ft	9.7 min.	319 Pa	10.4 min.	217 Pa
Argon	40%	166 sq in	7.0 ft	7.3 min.	373 Pa	10.3 min.	247 Pa

Table 1: Comparison of hold time and peak pressure calculations for three different clean agents in a 2,200-cubic-foot enclosure

representative of the peak pressures that may be encountered. This pressure can be imposed upon the damper in a test box, or the entire enclosure can be pressurized, or a temporary pressure box can be constructed around the damper for testing purposes. A large flow at a fairly high pressure will be required to test these vents in their open position, so consider testing them in a test box. Once the position at test pressure of 125 Pa is determined, the vanes must be locked in that position while the damper leakage area is tested. If installed in a test box where there are no bias pressures, it can be tested in the direction of intended venting. If installed in the enclosure, it should be tested in both directions to compensate for any bias pressures and to achieve a more accurate test due to increasing the amount of data collected. Ensure the PRV is tested in the flow direction that will occur during discharge. There are dual-acting PRVs that will open in both directions, but their free vent area differs with respect to direction so they must be tested in both directions to see how open they are at 125 Pa.

Reduced Need for Air Sealing and Relief Vents

The 2008 and new 2012 editions of NFPA

The 2008 and new 2012 editions of NFPA 2001 reduce the need for air sealing and relief vents.

2001 reduce the need for air sealing and relief vents. In many cases, the slightly more complex procedure proposed by Retrotec that was accepted into the enclosure integrity procedure of NFPA 2001 will identify when enclosures will perform better than the older more conservative formula dictated. This means 10 to 40 percent less air-sealing to be performed and pressure relief vents will have to be installed a lot less often, saving money on both counts.

The example in Table 1 of a 2,200-cubic-foot enclosure, 10-feet high and protected with three popular agents, shows how the new standard's test procedure yields both longer retention times and lower peak pressures. In the example, the old formulae would fail both the hold time requirement of 10 minutes and a 250 Pa peak pressure limit in each case but pass it in each case with the new formulae. The old formulae assumed a square root relationship between pressure and flow, represented by a 0.5 exponent whereas most tight enclosures have exponents closer to 0.65. ❖

References

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