Clean Agent Enclosure Design

By Colin Genge

Clean Agent Discharge

Clean agent fire suppression systems are used in enclosures where a sprinkler system could cause damage to sensitive contents, such as rooms containing 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 (240 - 1200 Pa) to occur for a fraction of a second. The magnitude is dependent of the enclosure leakage area.

Once the enclosure is totally flooded, the agent will begin to leak out at a rate that primarily depends on 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 from the enclosure, as shown in Figure 1.

Until 1988, enclosures protected by clean agents used full discharge tests to determine the hold time. Since then, door fans have been used to measure the leakage area, which is entered into formulae found in Annex C of NFPA 2001[1] to predict the hold time.

Figure 1: Graphical representation of the NFPA 2001 Edition 2012 Annex C Clean Agent Standard model for descending interface where 100% Agent

leaks out the bottom of the enclosure causing 100% Air to be drawn in above the interface to replace the lost volume.

Peak Pressure During Discharge

It is common practice for peak pressure calculations to be done for inert agents, but not for halocarbon agents. Inert gas discharge can produce as much Peak pressure as inert agents.

Peak pressure varies over time depending on the ratio between the leakage area of the enclosure and the volume of the room (LVR). In a typical halocarbon agent discharge, as shown in Figure 2, the peak pressure increases with enclosure tightness. This determines the hold times as shown in the legend. 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.

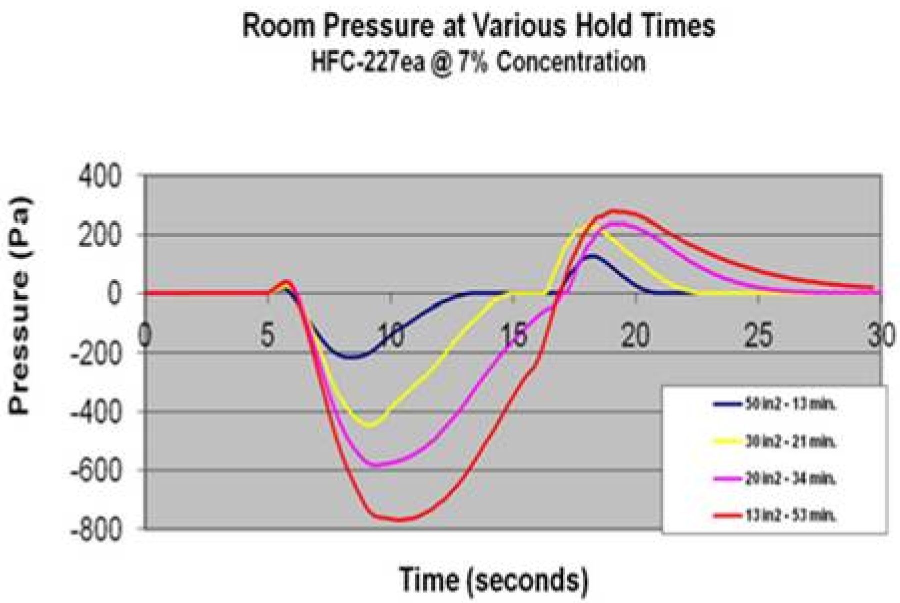

Fig 2: Typical halocarbon discharge

A 5 year research project, carried out to provide a validated prediction model for peak pressure based on leak to volume ratio. This research uncovered many important facts about clean agent discharge pressures and the peak pressure formulae previously used to predict pressure values during enclosure design and testing. In particular, this research found that:[2]

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

Sufficient data was gathered to more accurately predict the peak pressure for all agents. Figure 3 shows the new curve (in white) developed for inert agent peak pressure versus leak to volume ratio (LVR). Previously-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 4 shows the results of testing of peak pressures versus LVR for all tested inert agents in the research.

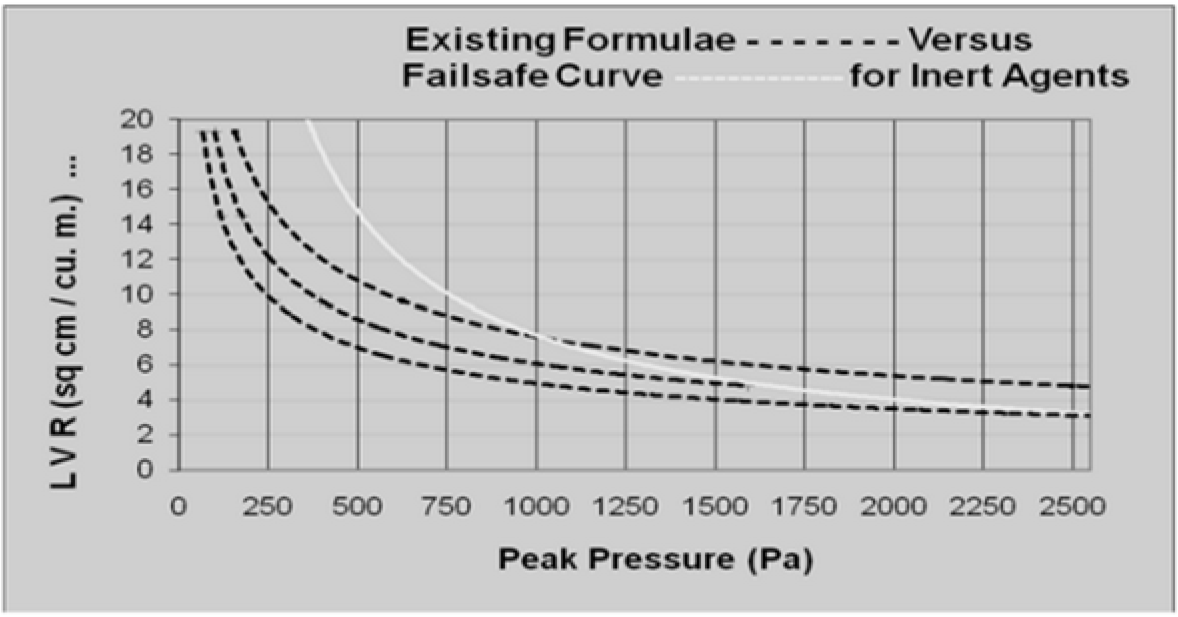

Figure 3: Peak Pressure is a function of LVR (Leakage to Volume Ratio).

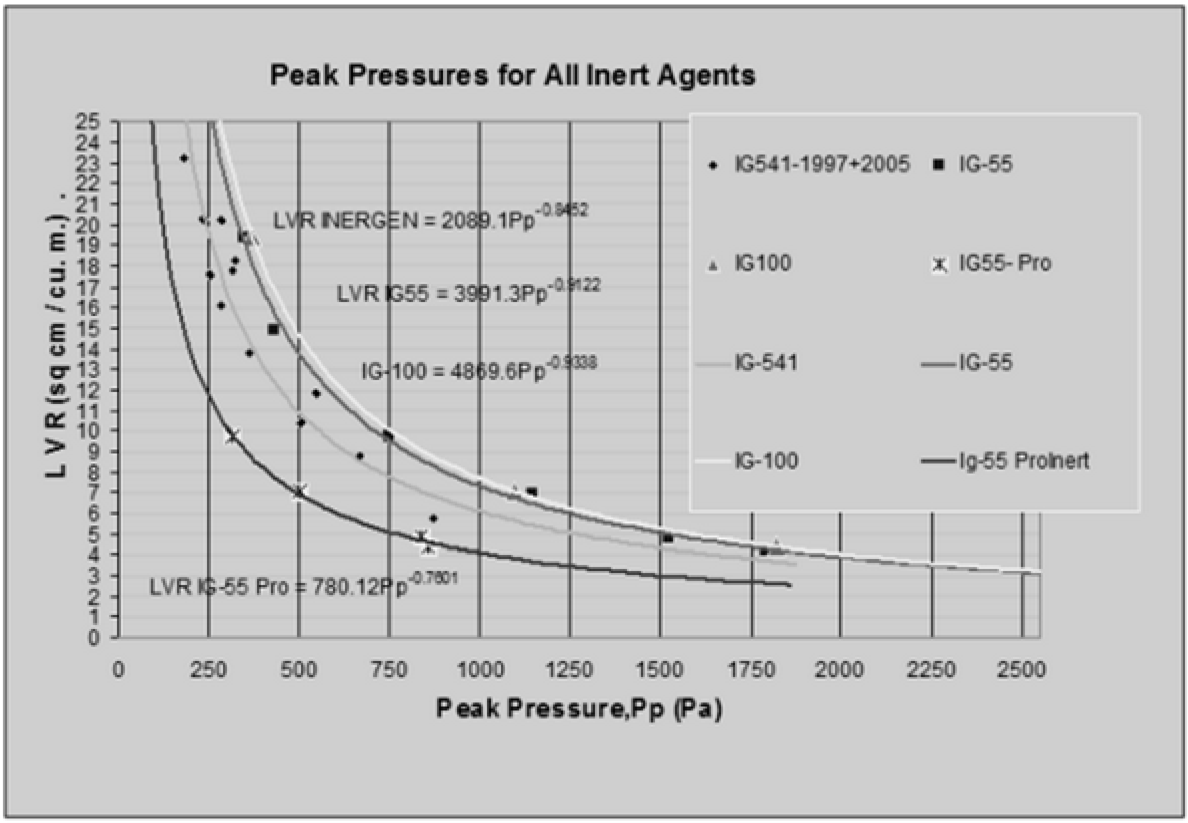

Figure 4: Peak Pressure curves for all tested inert agents.

A second leakage area must now be measured

NFPA 2001[1] 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 accidental enclosure leakage 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 allow 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 built.

The 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". The designer can perform calculations using the new peak pressure equations that have come out of the research project to determine whether or not a pressure relief vent (PRV) is likely to be needed and alter the design using the approaches presented in this article. It is no longer sufficient to simply specify a PRV of a certain size - its leakage rate must also be measured after installation to confirm the vent both opens at the correct pressure and has a large enough leakage path to outdoors to prevent the peak pressure from exceeding the specified limit.*

Optimizing Peak Pressure and Hold Time performance

Clean agent discharges can produce damaging 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; the enclosure can then be made tight to provide the specified hold time. Another solution is to 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 was 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 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.

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 research project[2] showed that the actual peak pressures exceeded those predicted by the previously used formulae by at

least 100%, and many of those enclosures were discharge tested with inert agents, it is safe to say that a wide range of enclosures handled 0.07 PSI (500 Pa) of peak pressure. This has also been verified with the use of a high output fan to pressurize enclosures where no effects were observed at 0.07 PSI (500 Pa). One can therefore assume that a double sided wall, securely fastened top and bottom, will handle 0.07 PSI (500 Pa). This can also be tested using a high pressure door fan.

While thicker walls can take more pressure[3] as shown in Table 1, false ceilings can only take about 0.007 PSI (50 Pa), so they must be protected from pressures higher than that with vented tiles.

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

Table 1: Wall Strength[3]

Selection of an appropriate hold time

NFPA 2001 requires a hold time of 10 minutes or a time period to allow for response by trained personnel. However, 10 minutes may not always be the appropriate hold time. The designer must consider what the response time for trained personnel to determine if longer hold times are

necessary. Shorter hold times might be appropriate for small enclosures always occupied. Reducing the hold time could 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 very difficult.

Enclosure design approaches

The following design strategies 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*

These strategies are meant to be considered during the design phase. The installed performance of the PRVs must be checked during installation to determine that 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 check adequate retention time.

- *Seal the walls to the upper slab. Extending walls to the upper slab and sealing them is the only defense from fire and smoke entering from outside the enclosure. Paragraph C-1.2.1 (2) in NFPA 2001 states "...enclosures absent of any containing barriers above the false ceiling, are not within the scope of Annex C,"[1] meaning the enclosure will be difficult to test and verify.*

- *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 offset by the increased air sealing costs needed for adequate hold time, and may also require PRVs more often. If a false ceiling is needed, nozzles should be specified above the ceiling; that's how virtually all systems are designed in Europe.*
- *Use an automatic door closing system. Doors often get wedged or propped open when the enclosure is in use. This practice impairs the clean agent system's. A better solution is an automatic door release mechanism that will close the doors whenever the first alarm sounds. A mechanism should be specified that will close the door when it is de-energized so it is failsafe.*

- ***If a false ceiling is specified, lower leaks should be sealed first until the specified hold time is reached and then leaks above the false ceiling should be sealed until the peak pressure limit is reached. The air leakage determination will require measuring upper and lower leaks separately, as described in Section C.2.7.2 of NFPA 2001 and shown in Figure 5.***

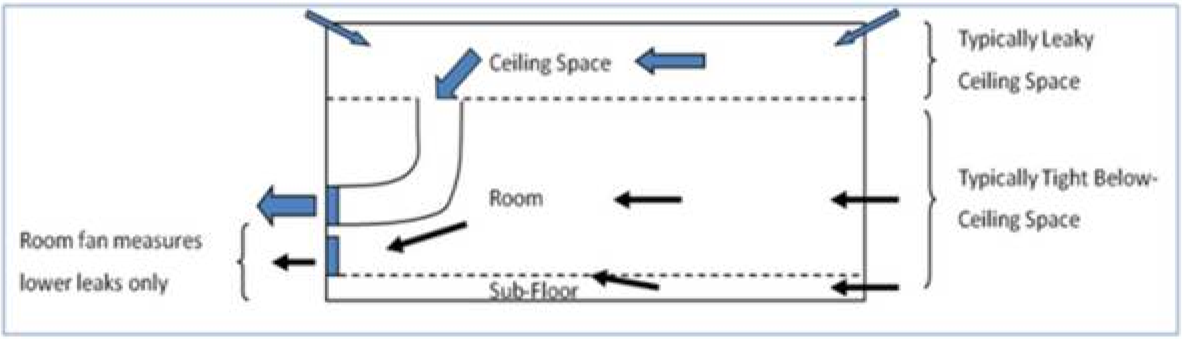

Figure 5: One door fan depressurizes the room while the second depressurizes above the ceiling so the pressure across the ceiling is zero, which allows determination of the room leaks separate from above-ceiling leaks.

- ***Increase the initial concentration of agent a further 15% 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 margin 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% of the enclosure height, allowing 40 to 25% of the agent to run out before the equipment is no longer protected. If additional agent were not added, only 15% 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% of the design concentration. NFPA 2001 uses an integration formula that increases the hold time prediction, but it is still important to add this additional agent, otherwise the enclosure will fail the hold time after only 15% of the total weight of agent is lost.***

If no mixing will occur, the height of the protected equipment should be kept to a minimum. If the equipment height exceeds 75% of enclosure height, continual mixing may be the only way to achieve a reasonable retention time.

Pressure Relief Vents

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 0.007 PSI (50 Pa) so they don't open unintentionally under normal HVAC pressures and no higher than 0.02 PSI (100 Pa) so the pressure is vented early enough to prevent it from becoming excessive.*

- *Specify the correct direction for venting with the PRV. Inert agent discharges always create positive pressures and must have venting 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 outdoors has not been accidently restricted*

Peak pressure evaluation

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. 0.002 PSI (125 Pa) is the pressure generally used to test PRVs because it is 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. A large flow at a fairly high pressure will be required to test these vents in their open position, so testing them in a test box can be advantageous. Once the position at test pressure of 0.002 PSI (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 by increasing the amount of data collected. The PRV should be 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.

References

1. *NFPA 2001, Standard on Clean Agent Fire Extinguishing Systems, National Fire Protection Association, Quincy, MA, 2012.*
2. *Pressure Relief Vent Area for Applications Using Clean Agent Fire Extinguishing Systems, Fire Suppression Systems Association, Baltimore, MD.*
3. *Robin, M.; Forssell, E. & Sharma, V. "Pressure Dynamics of Clean Agent Discharges," NIST SP 984-3, Halon Options Technical Working Conference, 15th Proceedings, National Institute of Standards and Technology, Gaithersburg, MD, 2005.*