Clean Agent Enclosure Design for ISO 14520 & AS4212

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The Clean Agent Discharge

Clean agent fire suppression systems are required in enclosures where a sprinkler system would cause damage to sensitive contents such as computer servers or historical artifacts. Upon fire detection the compressed agent, which can be a halocarbon or an inert gas, is released into the enclosure causing a peak pressure of around 250 to 1250 Pascals to occur for a fraction of a second, the magnitude of which is dependent upon total enclosure leakage area. Once the enclosure is completely flooded, the agent will begin to leak out at a rate that primarily dependent upon lower enclosure leakage area. 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 an interface that descends in time. Up until 1988, enclosures protected by Clean Agents used full discharge tests to determine the Hold Time but since 1988, Door Fans have been used for measuring the leakage area which is entered into formulae in Annex E of ISO 14520 to predict how long the agent will stay in the enclosure (Hold Time).

Figure 1: Clean Agent discharge causes cooling due to decompression.

Peak Pressure develops during discharge

It is common practice for peak pressure calculations to be done for inert agents but these calculations have rarely been done for halocarbon agents and that is a big problem since they can, in some cases, produce as much peak pressure as inerts. A 5 year research project, in which the author played a major role, involved many of the industry manufacturers (including: Fike, 3M, Ansul, Kidde Fenwal, Chemetron, Retrotec) and uncovered many important facts.

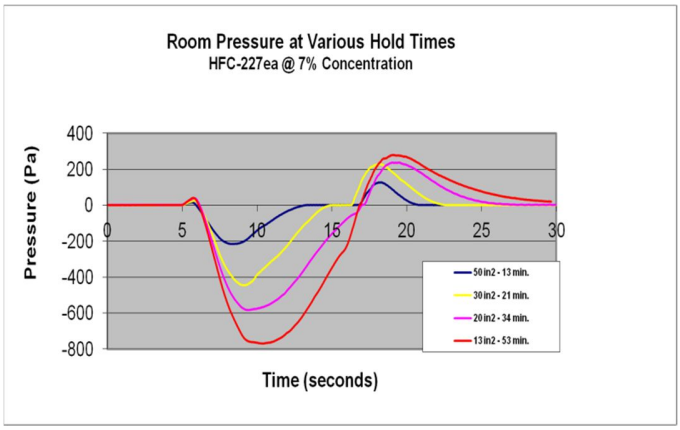


Figure 2: Peak Pressure increases with enclosure tightness

1. Existing inert agent formulae under-predicted peak pressure
2. Under certain conditions, halocarbon agents could produce as much peak pressure as inerts
3. Peak pressure from Halocarbons was extremely dependent upon humidity

Sufficient data was gathered to accurately predict the peak pressure for all agents and to develop a more refined Hold Time model.

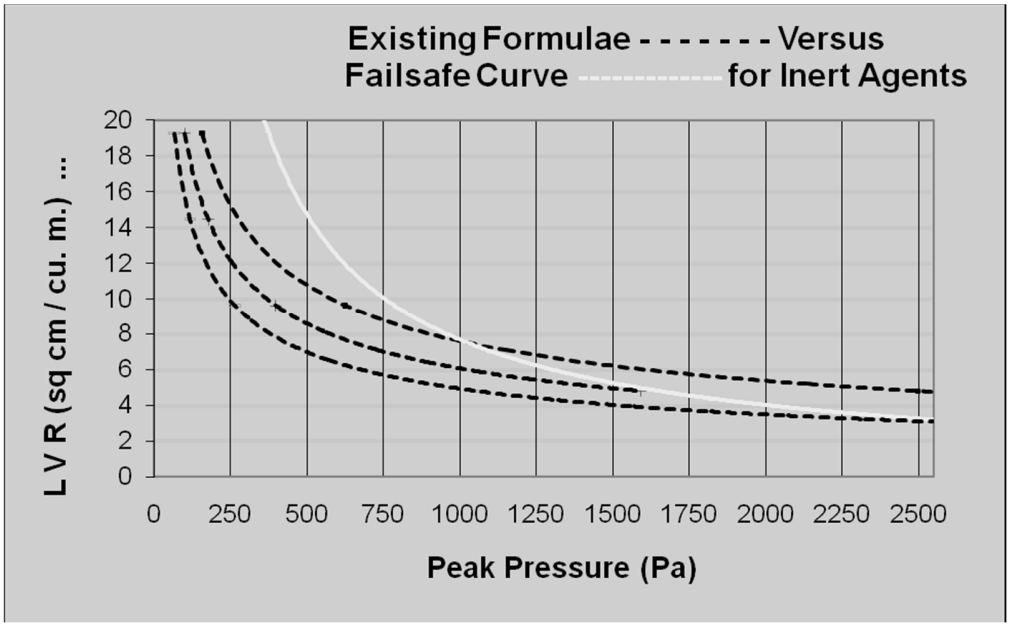


Figure 3: Peak pressure is a function of LVR (Leakage to Volume Ratio). Notice how the existing formulae all under-predict at typical Peak Pressure values that range from 250 to 500 Pa.

Annex A of ISO 14520 Section A.2 Working Documents lists:
"n) enclosure pressurization and venting calculations" shall be included which will, in turn, dictate the Minimum Allowable Leakage Area the enclosure must have according to the new peak pressure equations that have come out of the research project. This Leakage Area can be provided by accidental enclosure leakage and/or the area of any dampers that will be open during the discharge period although relying on the vent area of the dampers is the most common method. The Enclosure Integrity Procedure in Annex C is ideal for creating two leakage area values, one used for the calculation of the Hold Time and another used for evaluating Peak Pressure. These values must be measured after the enclosure has been completed. Clearly it would be extremely bad news to find out that a completed enclosure needed to have a PRV installed a few days before occupancy, but fortunately the designer can run calculations in advance to determine whether a PRV is likely to be needed or not and alter the design using the tips presented in this article.

It is not wise to simply specify a Pressure Relief Vent (PRV) of the correct size but its leakage rate must be measured after installation to ensure 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. This will now become an additional part of the Enclosure Integrity Procedure which is being done already and requires the same type of door fan equipment, albeit with more power in many cases, but very little in added time.

The new peak pressure values are now in the FIA Guidance on Pressure Relief in the UK as well as the FSSA Guidance in the US. For the first time, comprehensive formulae have been published and these formulae are currently embedded in Retrotec's FanTesticIntegrity software.

Selection of an appropriate Hold Time

After a typical 10 second discharge for halocarbons or 60 seconds for inerts, the Hold Time begins. Even though this time was almost always specified as 10 minutes, this value is not always the correct Hold Time. The designer must consider what the "10 minutes unless otherwise specified by the authority" will actually be because much longer Hold Times are required for remote sites or those with heavy fuel loads while much shorter Hold Times should be considered for small enclosures that are manned 24-7 but the Standard makes no provision for shorter retention times. Reducing this Hold Time to 6 minutes for a small 35 cubic meter enclosure and to 3 minutes for 10 cubic meter 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.

Figure 4: ISO 14520, 2000 edition model for descending interface where 100% of the initial concentration leaks out the bottom of the enclosure which replaces the lost volume with 100% above the interface.

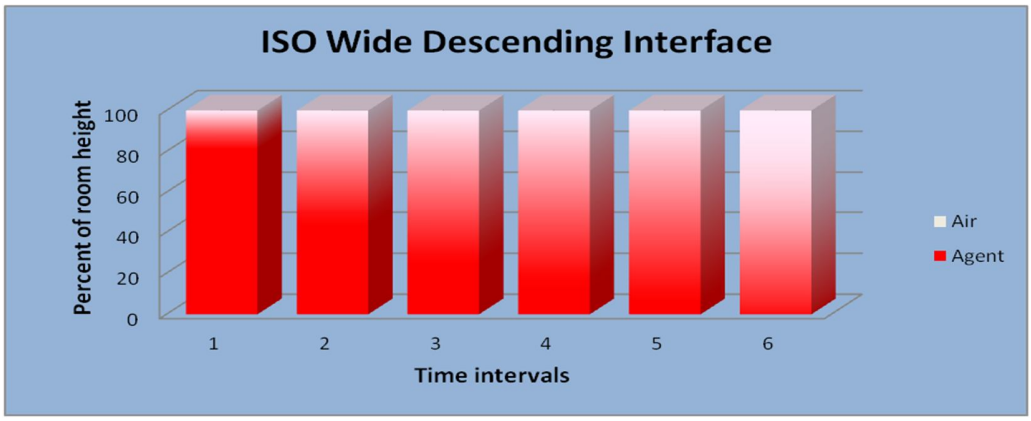
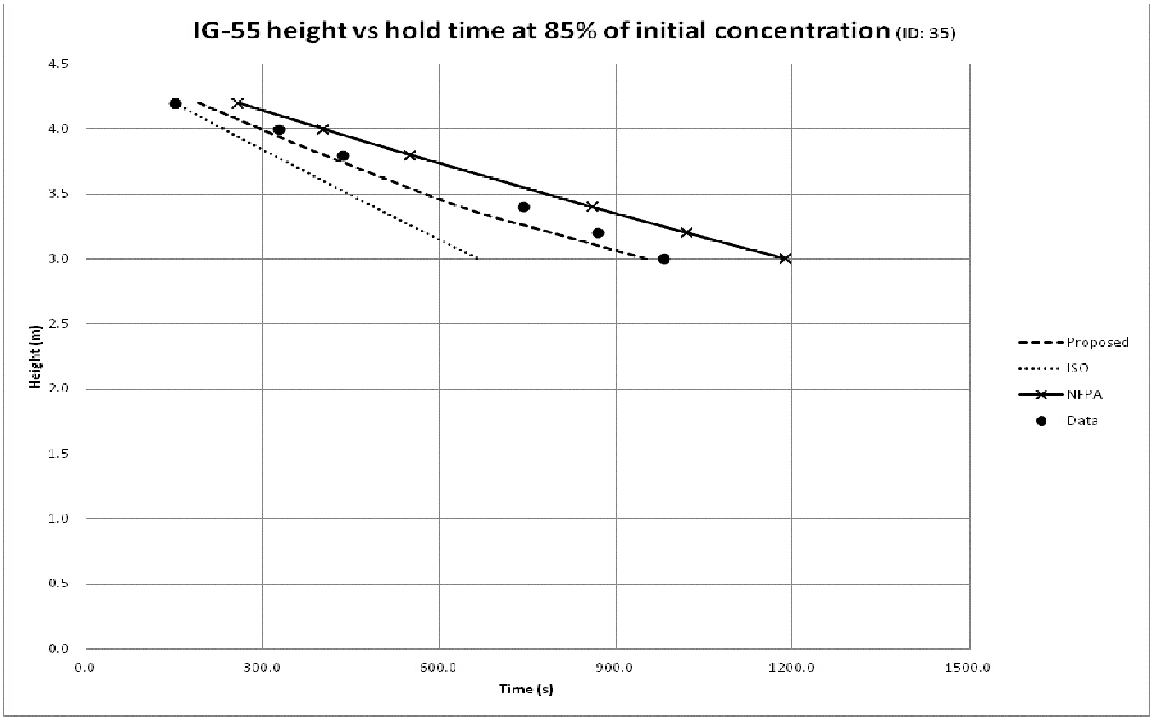


Figure 5 the current version uses the Wide Interface which decreases retention time by about 40% forcing enclosures to be 40% tighter and more difficult to pass.

The Wide Descending Interface was introduced into ISO 14520 Annex E in 2003 to allow for predictions of Hold Times for any drop in initial concentration. It was based on a theory that the original NFPA equations predicted the center of the interface. Instead of having a Sharp interface with the initial concentration below and 0% concentration above the interface, it assumed that the concentration at the interface was half the initial which slowly decreased to 0% at the top of the enclosure. The interface thickness was then double distance from the predicted interface to the ceiling. The concentration was then assumed to increase proportionally from 0% at the ceiling to 100% of the initial concentration at the bottom of the interface. Since the point of interest was typically 85% of the initial, it was necessary for the 50% point in the interface to fall much less for any given concentration where the final was

greater than 50% of the initial concentration. This math was accomplished by cleverly calculating an effective height of interest, H_e that was entered into the NFPA equations to trick them into calculating a Wide Interface Hold Time. The effect of this was to decrease predicted Hold Times by up to 40% which required enclosures to be much tighter than before, adding air sealing costs and increasing the size of PRVs that would then have to handle the increased pressure.

A saving grace that came out of this was that the research also showed that the NFPA Sharp Interface model previously followed in the CA2001 software and referenced in AS4214, was actually much closer to the test data than the ISO Wide Interface Model as shown in the proceeding graph for a typical inert. The dots are the experimental data and the solid line is the old equation while the new proposed (and accepted but not yet published in NFPA 2001 or ISO14520) equation is the dashed line in the middle.



When it's considered that this is the worst case for leakage and most often the actual data will show much more retention, there is a good case for keeping something closer to the original NFPA Sharp Interface equation which is shown by the solid line. Halocarbons such as HFC227ea (FM-200) are even closer to the Sharp Interface equation. A compromise solution was arrived at that reduced the conservatism of the existing standard and accurately represented the recent hold time test data while maintaining a reasonable failsafe margin.

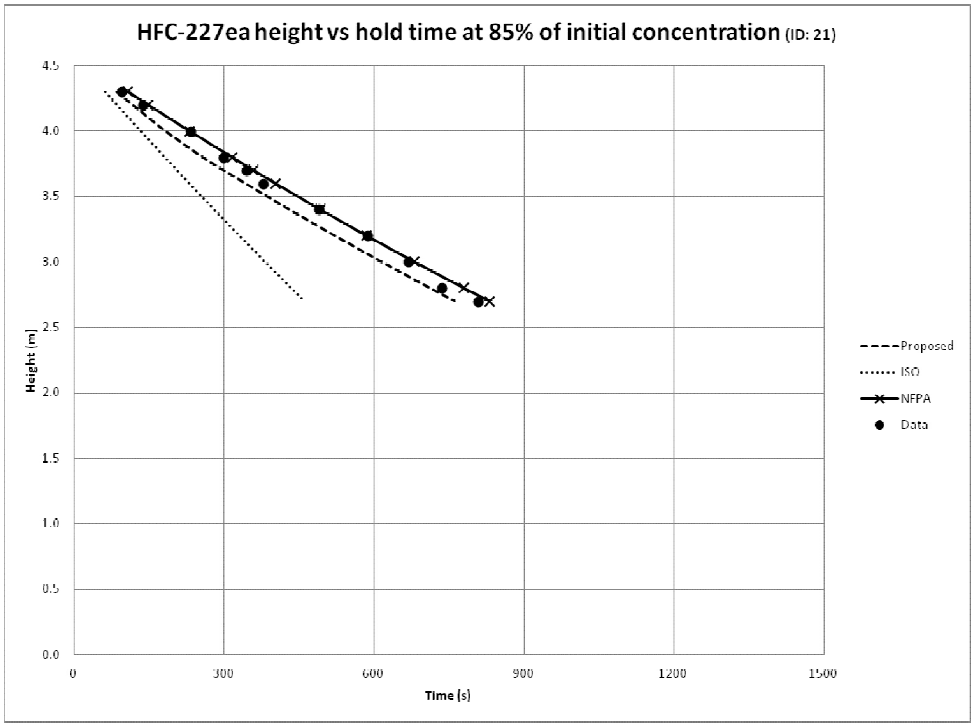


Figure 6 Halocarbons show a good correlation to the old formula

A graphical representation of the two interfaces is shown in Figure 7. The ISO Wide Interface on the right is the most conservative while the Actual interface is much thinner and is closer to the NFPA Sharp Interface which would be positioned on a line at the 50% point on the ISO graphic. In actual discharges the Sharp Interface prediction used by NFPA is much closer to what can be expected although it is theoretically possible for the interface to occur on the Proposed line but unlikely. ISO offers a wide margin of safety with respect to Hold Time but loses out because it forces enclosures to be much tighter which presents a larger danger of overpressure.

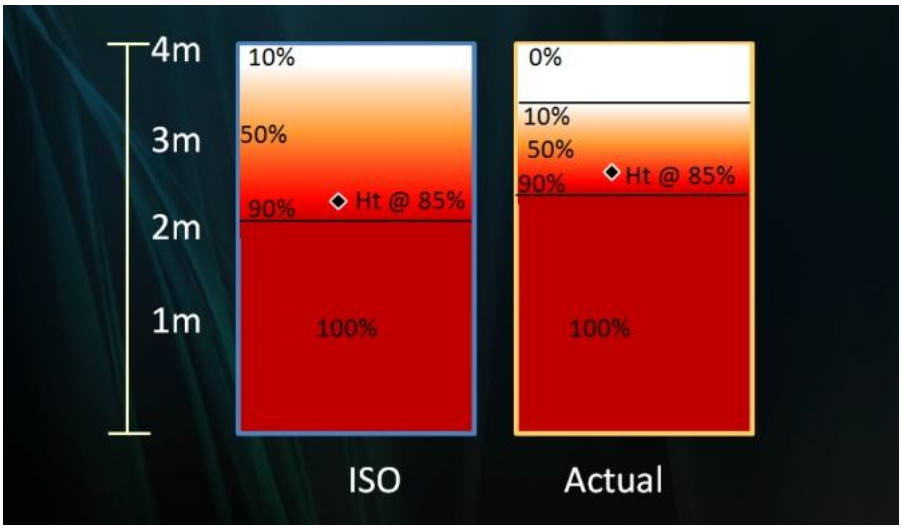


Figure 7 Visualizing the existing Wide interface and the new interface uncovered during the research.

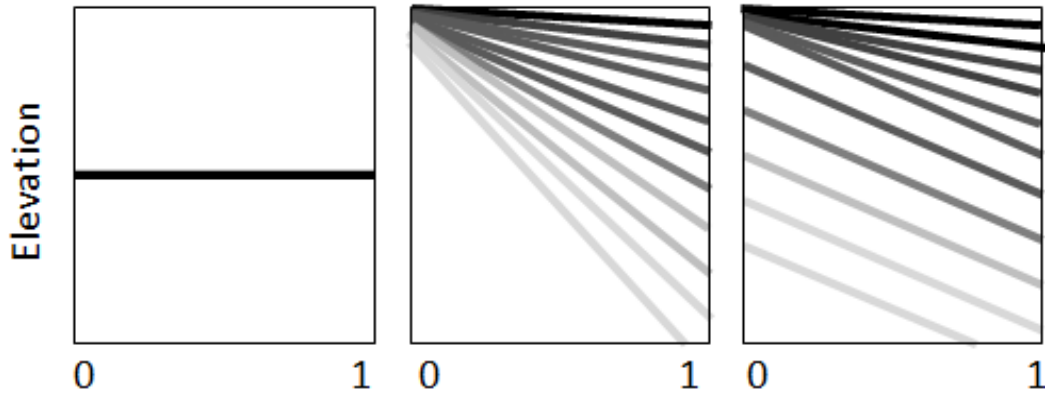


Figure 8. Graphical demonstration of the three descending interface models. From left to right: Sharp Interface, Wide Interface, and Thick Interface. The x-axis represents fraction of agent remaining.

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 pressure relief vent (PRV) that will provide increased leakage to reduce the peak enclosure pressure; which 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 effort still requires the use of PRVs, optimizing the enclosure will increase the degree of fire protection and possibly allow the use of smaller PRVs with more passive protection built in.

Currently, many inert agent protected enclosures have PRVs installed where they are not needed but other enclosures (both inert and halocarbon) need PRVs but they are not installed. This situation should be resolved by using the new Enclosure Integrity evaluation procedure along with the new Peak Pressure formulae.

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.

The fail safe approach is to ignore enclosure leakage and to rely completely on venting to relieve the pressure (seal tight and vent right). While this is the best solution in theory because containment of the hazard is maximized, it does leave the enclosure vulnerable in most cases to over pressure in cast the PRV fails which might be more damaging because of the frequency of false discharges than the fire hazard itself. Potentially motorized vents are likely to fail compared to gravity weighted vents. Either way, an evaluation done on the enclosure will identify the degree of risk in case of PRV failure. This also points to the importance of testing the relief vent path annually to ensure it is not blocked (as if often is) after checking to see if the PRV opens as its designed to do (as it often doesn't).

Vent selection

Not all vents are created equal, and the procedure of testing vents during commissioning and annual inspections will start to highlight the differences in performance between various vent types.

The selection of a quality vent is a critical part of pressure relief that is often overlooked. Simply knowing the required Free Vent Area (FVA) is not enough. Many passive (non-powered) vents are not balanced, and will require a tremendous pressure to actually achieve their advertised FVA, which can result in damaging pressure buildup before the vent has a chance to fully open. A low (50-100Pa) opening pressure is ideal for this application, and a balanced blade system will ensure that the vent opens fully soon after the opening pressure is reached. When selecting a passive vent, make sure to ask the manufacturer for the following information:

- Free vent area
- Opening pressure of the vent blades (ideally between 50-100Pa)
- Pressure needed to fully open the vent (ideally not more than 150Pa)

Enclosure design rules

Specify sealing of the walls to the upper slab. Extending walls to the upper slab and sealing them airtight is the only defense from fire and smoke entering the enclosure from the outside. Refer to C-1.2.1 (2) in NFPA2001 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. This statement does not specifically appear in the ISO and EN standards but can be inferred by the tone of the document.

Flooding to the maximum reasonable height will reduce the need for airsealing and reduce the size of the PRV, saving on installation costs.

Reduce the height of the protected equipment.

Doors often get wedged or propped open when the enclosure is in use. This practice impairs the clean agent systems ability to put the fire out. A better solution is automatic door release mechanisms that will close the doors whenever the first alarm sounds. Choose a door opener that will close the door when it is de-energized so it is failsafe.

If a False Ceiling is specified, seal lower leaks first until the specified Hold Time is reached *to reduce reliance on the PRV*. Use Section E.3.4.3 where the leaks are "temporarily sealed" using a second fan for neutralization which will increase the Hold Time but not the Peak Pressure.

Ensure the False Ceiling has at least 5% open area to prevent it from being dislodged as the discharge vents upwards.

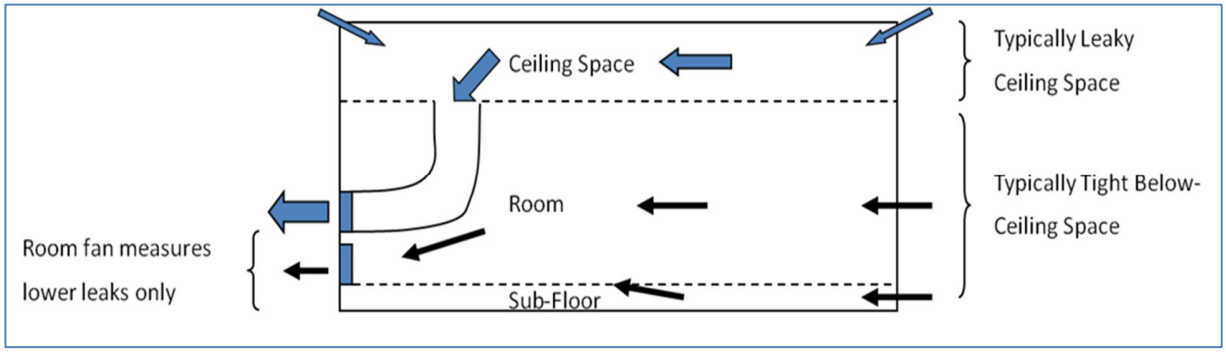


Figure 9: One Door Fan depressurizes the room while the second depressurizes above the ceiling so the pressure across the ceiling is zero which effectively seals off the upper leaks allows the lower fan to measure the room leaks separate from above ceiling leaks.

Determine whether it's likely that the agent will be continually mixed during the Hold Time. If air handlers continue to run, then continual mixing is certain but even equipment cooling fans or thermal effects can be sufficient to cause continual mixing and in those cases the initial concentration must be increased. The standard specification requires that the final concentration at the end of the Hold Time is 85% of the design concentration or in Australia cannot fall below "C_{min}" which is the agent's minimum extinguishing concentration. For continual mixing the initial concentration must be increased. Enough agent must be discharged so the initial concentration is at least 15% over the design concentration.

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

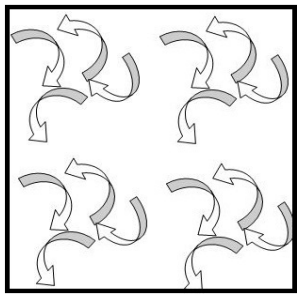


Figure 10 As agent is lost, air continually mixes with the agent to provide the same concentration everywhere in the enclosure.

Pressure Relief Vent (PRV) tips

If PRVs must be installed, there are several rules to follow to optimize their performance. Install vents as high as possible so that the lighter air, not the more dense 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. Inert discharges always create positive pressures and must vent 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. Ensure the correct direction for venting with the PRV is specified. 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 which is quite common.

Figure 11: the sign says "DO NOT OBSTRUCT", because it is very likely the vent path will be obstructed which is why the vent path must be checked regularly.

When selecting a vent always ensure that the vent manufacturer has test data behind their performance statements. Venting to atmosphere may not be straight forward and venting through additional rooms before reaching atmosphere may be the only option available to designers. Cascading venting can be planned for and the FIA UK guidelines give designers guidance on sizing vents for this specific situation.

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 the open at the prescribed pressure. 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 the increased 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 there 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.

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 5 year research project showed that the actual pressures exceeded those of 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 500 Pa of peak pressure with ease. This can also be verified by using a high power fan to pressurize enclosures where we have noticed no effects at 500 Pa. We can therefore assume that a double sided wall that is securely fastened top and bottom will handle 500 Pa and that this can be used

as a "*specified enclosure pressure limit".* If in doubt, test a wall section under the specified enclosure pressure limit but this will require a specially designed fan or high power Door Fans can be used in series.

While thicker walls can take more pressure, False Ceilings can only take about 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

Figure 12: the Wall Strength from 1997 HOTWC paper. One PSF = about 48 Pascals.

The previous edition of AS4214 provided the following conservative enclosure pressure limits. Although it has not been re-published in AS ISO 14520-2009, it can still be used as a guideline.

Construction type	Typical structures	Allowable over-pressure, Pa
Light	Lightweight partitions including glazing	250
Normal	Brick	500
Vault	Reinforced concrete	1000

Figure 1313: the Wall Strength published in AS4214 and taken from the University of Manchester and the UK building code

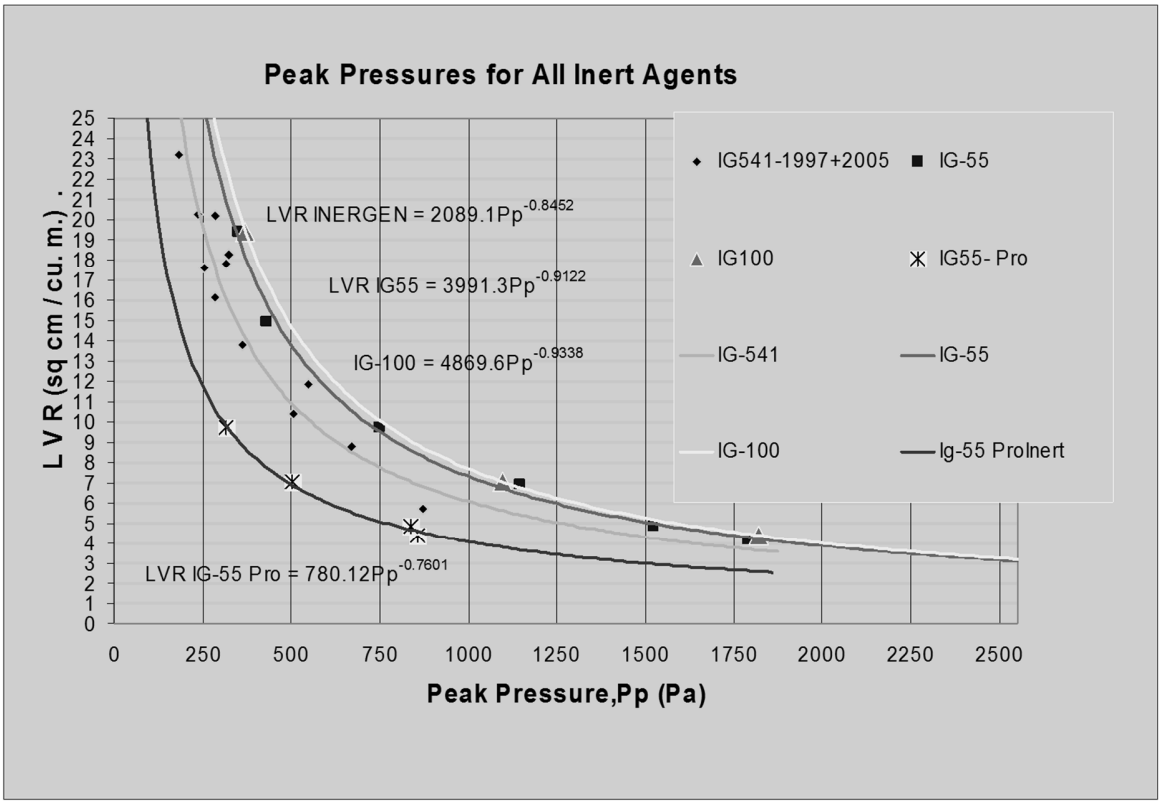
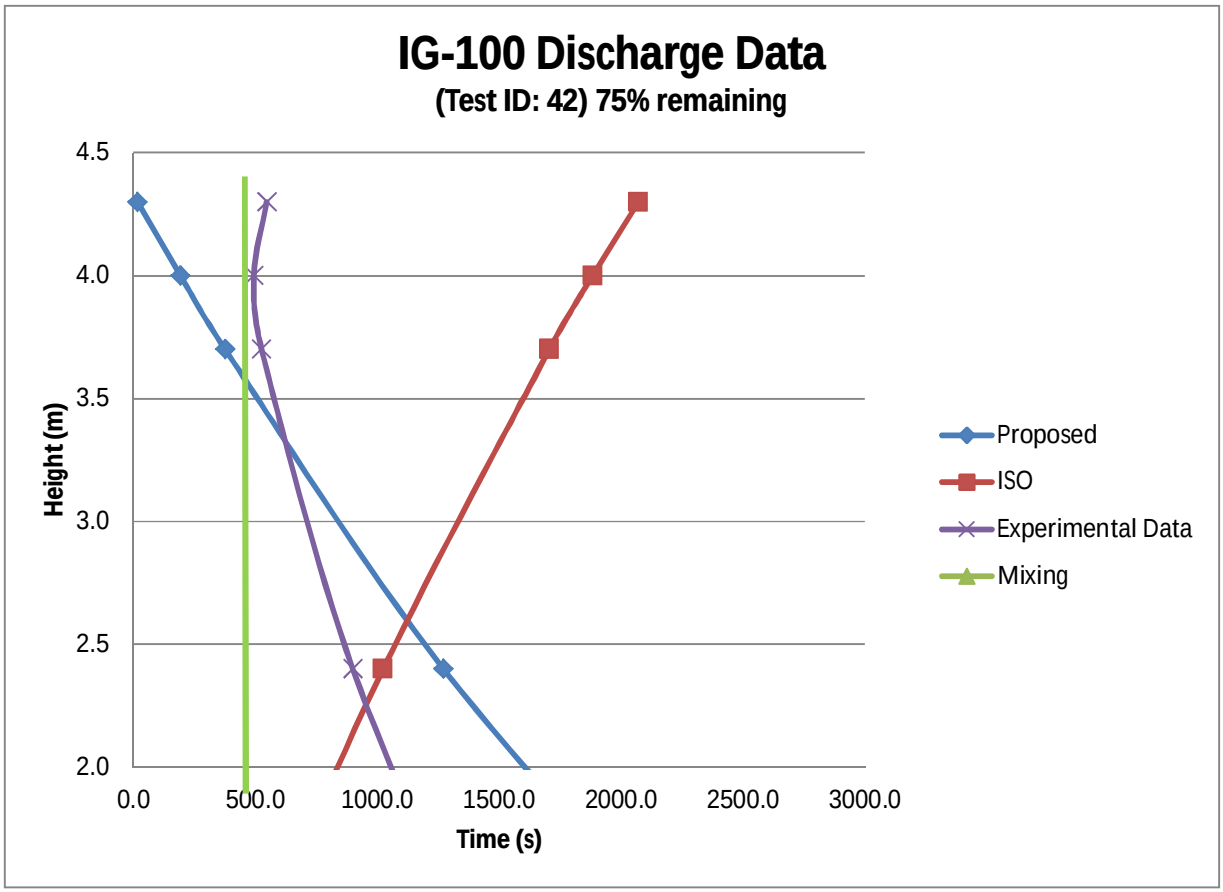


Figure 14: Peak pressure curves for all tested inert agents.

Removal of formulas for extinguishants lighter than air

Testing has shown that the assumption used in the current ISO standard that a lighter than air agent such as Nitrogen would rise, was incorrect. Because of cooling during discharge, the data clearly shows a descending interface for Nitrogen [IG- 100] up to at least 0.75 of the initial concentration remaining. After the concentration degrades beyond 0.75, the concentration in the middle of the enclosure stays more or less constant with a slight degradation in concentration at the top and bottom. Finally, as the concentration degrades below 0.5 of agent remaining, the interface begins to ascend but by this time the remaining concentration is well below the point of interest. It must therefore be assumed that either the interface is descending or that no reliable interface is established at all which would require a continual mixing calculation to be performed making current ISO interface calculation irrelevant. In either case, there is ample justification to remove all of the equations that refer to an ascending interface because there is simply no evidence of one occurring.



Notice that in both cases the existing ISO formula actually goes in the opposite direction. The vertical green line on the above graph shows how the continual mixing equation would relate to the actual experimental data. The driving force is the difference in density between the nitrogen mixture and air with no consideration as to the location of the leaks.

Conclusion

Currently, peak pressure equations are under-predicting peak pressures experienced during discharges. The FSSA and FIA publications are available and can be used for planning pressure relief venting design as the early stages of a project.

The ISO Hold Time models are too conservative whereas the NFPA equations are much closer. Using ISO equations but leaving out the effective height calculation (He) gives the same results as NFPA. ISO 14520 and NFPA 2001 standards will be revised in the future to reflect a "Thick Edge" interface.

Door fan procedures are available to accurately measure Pressure Relief Area to determine whether the enclosure is safe from the greatest hazard which is usually over pressure during discharge. A door fan test is a great way of determining whether a pressure relief vent will provide the suggested free vent area needed for a specific hazard.

References

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