भारतीय मानक ब्यूरो
(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)
BUREAU OF INDIAN STANDARDS
(Ministry of Consumer Affairs, Food & Public Distribution, Govt. of India)

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व्यापक परिचालन मसौदा

हमारा संदर्भ : सीईडी 22:एच/टी-1 **09 सितम्बर 2024**

तकनीकी समिति : अग्नि शमन विषय समिति, सीईडी 22
प्राप्तकर्ता :

1. **सिविल अभियांत्रिकी विभाग परिषद, सीईडीसी के सभी सदस्य**
2. **अग्नि शमन विषय समिति, सीईडी 22 और इसकी उपसमितियों के सभी सदस्य**
3. **रुचि रखने वाले अन्य निकाय।**

महोदय/ महोदया,

निम्नलिखित मानक का मसौदा संलग्न हैं:

प्रालेख संख्या	शीर्षक
सीईडी 22(26518)WC	आईएस 15493: 2021 गैसीय अग्नि शमन प्रणाली - सामान्य आवश्यकताएँ (*पहला पुनरीक्षण*) के पहले संशोधन का व्यापक परिचालन मसौदा [*आईसीएस: 13.220.10]*

कृपया इस मसौदे का अवलोकन करें और अपनी सम्मतियाँ यह बताते हुए भेजे कि यह मसौदा प्रकाशित हो तो इन पर अमल करने में आपको व्यवसाय अथवा कारोबार में क्या कठिनाइयां आ सकती हैं।

सम्मतियाँ भेजने की अंतिम तिथि: 09 अक्टूबर 2024

सम्मति यदि कोई हो तो कृपया अधोहस्ताक्षरी को ई-मेल द्वारा ced22@bis.gov.in पर या उपरलिखित पते पर, संलग्न फोर्मेट में भेजें। सम्मतियाँ बीआईएस ई-गवर्नेंस पोर्टल, www.manakonline.in के माध्यम से ऑनलाइन भी भेजी जा सकती हैं।

यदि कोई सम्मति प्राप्त नहीं होती है अथवा सम्मति में केवल भाषा संबंधी त्रुटि हुई तो उपरोक्त प्रालेख को यथावत अंतिम रूप दे दिया जाएगा। यदि सम्मति तकनीकी प्रकृति की हुई तो विषय समिति के अध्यक्ष के परामर्श से अथवा उनकी इच्छा पर आगे की कार्यवाही के लिए विषय समिति को भेजे जाने के बाद प्रालेख को अंतिम रूप दे दिया जाएगा।

यह प्रालेख भारतीय मानक ब्यूरो की वैबसाइट www.bis.gov.in पर भी उपलब्ध हैं।

धन्यवाद।

भवदीय
ह/-
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सलंग्न: उपरिलिखित

भारतीय मानक ब्यूरो
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WIDE CIRCULATION DRAFT

Our Reference: CED 22:H/T-1 **09 September 2024**

TECHNICAL COMMITTEE: FIRE FIGHTING SECTIONAL COMMITTEE, CED 22

ADDRESSED TO:

1. All Members of Civil Engineering Division Council, CEDC
2. All Members of Fire Fighting Sectional Committee, CED 22 and its all Subcommittees
3. All others interested.

Dear Sir/ Madam,

Please find enclosed the following draft:

Doc No.	Title
CED 22(26518)WC	Draft Amendment No. 1 to IS 15493: 2021 Gaseous Fire Extinguishing Systems — General Requirements (*First Revision*) *[ICS: 13.220.01]*

Kindly examine the attached draft and forward your views stating any difficulties which you are likely to experience in your business or profession if this is finally adopted as National Standard.

Last Date for Comments: 09 October 2024

Comments if any, may please be made in the enclosed format and emailed at ced22@bis.gov.in or sent at the above address. Additionally, comments may be sent online through the BIS e-governance portal, www.manakonline.in.

In case no comments are received or comments received are of editorial nature, kindly permit us to presume your approval for the above document as finalized. However, in case comments, technical in nature are received, then it may be finalized either in consultation with the Chairman, Sectional Committee or referred to the Sectional Committee for further necessary action if so desired by the Chairman, Sectional Committee.

The document is also hosted on BIS website www.bis.gov.in.

Thanking you,

Yours faithfully,

Sd/-

Dwaipayan Bhadra
Scientist 'E' & Head
Civil Engineering Department
Email: ced22@bis.gov.in
Phone: +91-11 2323 5529

Encl: As above

FORMAT FOR SENDING COMMENTS ON THE DOCUMENT

[Please use A4 size sheet of paper only and type within fields indicated. Comments on each clause/sub-clause/ table/figure, etc, be stated on a fresh row. Information/comments should include reasons for comments, technical references and suggestions for modified wordings of the clause. **Comments through e-mail to** ced22@bis.gov.in **shall be appreciated**.]

Doc. No.: CED 22(26518)WC **BIS Letter Ref**: CED 22:H/T-1

Title: Draft Amendment No. 1 to IS 15493: 2021 Gaseous Fire Extinguishing Systems - General Requirements (*First Revision*) *[ICS: 13.220.01]*

Last date of comments: 09 October 2024

Name of the Commentator/ Organization: ______________________________

Clause/ Para/ Table/ Figure No. commented	Type of Comment (Technical/ Editorial/ General)	Comments/Modified Wordings	Justification of Proposed Change

NOTE- Kindly insert more rows as necessary for each clause/table, etc.

BUREAU OF INDIAN STANDARDS

DRAFT AMENDMENT FOR COMMENTS ONLY

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DRAFT AMENDMENT NO. 1 SEPTEMBER 2024

TO

IS 15493: 2021 GASEOUS FIRE EXTINGUISHING SYSTEMS — GENERAL REQUIREMENTS

(First Revision)

[*Page* 20, *clause* **10.2.10** (b)] — Insert the following below the point (b):

'c) *Door fan test for minimum hold time* — It is essential to determine the likely period during which the extinguishing concentration will be maintained within the protected enclosure. This is known as the hold time. The hold time shall be predicted by the door fan test specified in Annex F or determined by a full discharge test based on the following criteria.

i) The start of the hold time is when the concentration throughout the enclosure shall be the minimum design concentration.
ii) At the end of the hold time, the extinguishant concentration at the elevation of the protected hazard shall be not less than 85 percent of the design concentration.
iii) The hold time shall be not less than 10 min unless otherwise specified by the authority.'

[*Page* 20, *clause* **10.3**, *para* 1, *last sentence*) — Replace the existing with the following:

'The certificate shall give the design concentrations and, if carried out, reports of any additional test including the door fan test as per Annex F.

[*Page* 28, *Annex* E] — Insert the following new Annex F after the Annex E:

'ANNEX F

(*Clause* 10.2.10 (c) *and* 10.3)

DOOR FAN TEST FOR DETERMINING OF MINIMUM HOLD TIME

F-1 GENERAL

This annex contains information for establishing the integrity of rooms and enclosures for maintaining the extinguishant concentration for the relevant period (hold time). It includes details of testing and assumes that the air-handling plant will not be operating during the hold time.

This procedure cannot be used to predict what extinguishant concentrations might develop in adjoining spaces.

This procedure is only suitable providing:

a) an adequate return air path exists (*see* **F-2.4.2** and **F-2.7.1.3**), and

b) the fan unit(s) can develop an enclosure pressure of 25 Pa (this is a function of the size of the enclosure, its integrity, and the number and capacities of the fans. *see* **F-2.2.1** and **F-2.7.4.3**).

The calculation procedures used are suitable for both heavier-than-air extinguishants and extinguishants that are lighter than air. The hold time calculation models, for enclosures without continuous mixing, assume that the enclosure is either a standard enclosure or a non-standard enclosure. A standard enclosure has a uniform horizontal cross-sectional area with horizontal upper and lower boundaries. A non-standard enclosure is one with a non-uniform horizontal cross-sectional area and/or sloping upper and/or lower boundaries.

NOTE — For gas/air mixtures heavier than air, the calculation procedures have been verified by comparison of calculation results from door fan testing with hold times from real flooding tests. This has not yet been done for gas mixtures lighter than air.

F-2 TEST FOR DETERMINATION OF PREDICTED HOLD TIME

F-2.1 Principle

A fan is temporarily located within an access opening to pressurize and depressurize the enclosure. A series of pressure and airflow measurements are made from which the leakage characteristics of the enclosure are established.

The predicted hold time is calculated using these leakage characteristics on the following assumptions.

a) That leakage occurs under the worst conditions, that is when one half of the effective leakage area is at the maximum enclosure height, and the other half (the lower leakage area) is at the lowest point in the enclosure.
b) The direction of flow through the enclosure, during the hold time, is downwards for extinguishants heavier than air, and upwards for extinguishants lighter than air.
c) That all leak flow is one-dimensional, that is ignoring stream functions.
d) That flow through any particular leak area is either into or out of the enclosure and respectively either from or into an infinitely large space.
e) That the enclosure and surroundings are at a temperature of 20 °C, and atmospheric pressure is 1.013 bar absolute.

F-2.2 Apparatus

F-2.2.1 Fan unit, consisting of a frame that will fit into and seal an access opening in the enclosure, and one or more variable speed fans, with low flow facilities, capable of giving a differential pressure of not less than 25 Pa across the enclosure boundary.

F-2.2.2 Pressure measuring devices, two in number, one to measure enclosure differential pressure and one to measure fan flow pressure.

F-2.2.3 Flexible tubing, for connecting pressure measuring devices.

F-2.2.4 Chemical smoke pencils and/or smoke generator.

F-2.2.5 Thermometers, two in number, for measuring ambient temperatures.

F-2.2.6 Signs, reading "DO NOT OPEN — PRESSURE TEST IN PROGRESS" and "DO NOT CLOSE — PRESSURE TEST IN PROGRESS", displayed during the test operation.

NOTE — Additional apparatus, such as measuring tapes, a barometer for measuring atmospheric pressure, torches, ladders, tools to remove floor and ceiling tiles, computer or a calculating device, camera, can be necessary or convenient.

F-2.3 Calibration and Accuracy of the Apparatus

F-2.3.1 *Fan Unit*

The fan unit (*see* **F-2.2.1**) shall be calibrated at intervals and by the method recommended by the manufacturer. Records shall be kept and also copies of the appropriate calibration certificates. The flow rate shall be accurate to ± 5 percent of the measured value.

F-2.3.2 *Pressure Measuring Devices*

The pressure measuring devices (*see* **F-2.2.2**) shall be accurate to ± 1 Pa and shall be calibrated at regular intervals. Records shall be maintained and where appropriate calibration certificates. The pressure measuring device to measure the fan flow pressure can have a different accuracy as long as the requirements for the accuracy of the flow rate (*see* **F-2.3.1**) are fulfilled. The atmospheric pressure measurement shall be accurate to ± 100 Pa.

If inclined manometers are used, change the fluid at the intervals recommended by the manufacturer. Level and zero inclined manometers before each test.

F-2.3.3 *Temperature Measuring Devices*

Temperature measuring devices shall be accurate to ± 1 °C.

F-2.4 Preliminary Preparation

F-2.4.1 Obtain a description of air-handling equipment and extinguishant extraction systems, serving the enclosure and its surroundings, from the user.

F-2.4.2 Check for the following:

a) Raised platform floors and false ceiling spaces.

b) Visually obvious leaks in the enclosure.
c) Adequate return paths outside the enclosure between all leaks and the fan unit.
d) Conflicting activities in and around the enclosure.
e) Leakage areas in the hold time condition by visually checking the door closure or other opening selected for mounting the fan unit.

F-2.4.3 Provide the following information to the user:

a) Description of the test.
b) Time required to complete the test.
c) What assistance will be needed from the user's staff.
d) Information on any necessary disturbance to the building or its services during the test; for example removal of floor or ceiling tiles, a shutdown of air handling systems, holding doors open and/or shut.

F-2.5 Evaluation of Enclosure

F-2.5.1 *General*

Obtain or prepare a sketch plan showing the enclosure and its surroundings, the location of the door and other openings through which air will flow during the test, and the location of any ducts penetrating the enclosure, and any dampers in the ducts. Show the status (that is whether open, closed, on, off during the hold time) of each door, hatch, damper and other significant items (for example fans), and which access opening(s) is (are) to be used for the fan unit.

Show the location of the floor and sink drains.

F-2.5.2 *Mixing During Hold Time*

Enclosures with continuous mixing are enclosures in which there will be continuous good mixing for example due to strong heat sources or recirculating air handling equipment so that an interface does not form and a uniform extinguishant concentration is maintained throughout the enclosure during the hold time.

Enclosures without continuous mixing are enclosures in which there is partial or no mixing during the hold time so that an interface forms between the extinguishant/air mixture and the incoming air.

If it is uncertain whether the enclosure is one with or without continuous mixing, then perform the hold time calculations for both cases. Use the lower of the two hold time values.

F-2.6 Measurement of Enclosure

F-2.6.1 *Standard Enclosures without Continuous Mixing*

Standard enclosures are those with a uniform horizontal cross-sectional area and horizontal upper and lower boundaries. Measure the protected enclosure as necessary and record the following:

a) The overall height of the protected enclosure from its lowest to its highest point, H_o.
b) The required protected height from the lowest point in the enclosure, *H*.
c) The net volume of the protected enclosure, *V*.

F-2.6.2 *Non-standard Enclosures without Continuous Mixing*

Non-standard enclosures are those with the non-uniform horizontal cross-sectional area, such as enclosures with non-horizontal upper and/or lower boundaries. Measure the protected enclosure as necessary and record the following:

a) The overall height of the protected enclosure from its lowest to its highest point, H_o.
b) The required protected height from the lowest point in the enclosure, *H*.
c) The net volume of the protected enclosure, *V*.
d) The horizontal cross-sectional area, *A*, at various heights, sufficient to determine its variation with height so that V_e and dV_e can be evaluated using **Formulae (24)** and **(25)** (*see* **F-2.8.9.3**).

F-2.6.3 *Enclosures of any Shape with Continuous Mixing*

Measure the protected enclosure as necessary and record the following:

a) The overall height of the protected enclosure from its lowest to its highest point, H_o.
b) The net volume of the protected enclosure, *V*.

F-2.6.4 *Opening for Mounting the Fan Unit*

If the door or other closure, replaced by the fan unit for the test, has significant measurable leakage openings in the hold time condition, then these should be measured and recorded.

F-2.7 Test Procedure

F-2.7.1 *Preparation*

F-2.7.1.1 Advise supervisory personnel in the area of the test.

F-2.7.1.2 Remove papers and objects likely to be disturbed by the air stream from the fan.

F-2.7.1.3 Block open sufficient doors outside the enclosure envelope to provide an adequate return path for air between the fan unit and the enclosure boundaries while correcting any breach of any requirements of the facility, including requirements for security, fire protection and environmental boundaries.

F-2.7.1.4 Using the sketch plan (*see* **F-2.5**), set the enclosure air-handling equipment and extinguishant extraction systems to the state they would be in during the hold time, except that:

a) recirculating air-handling equipment without fresh air make-up or exhaust which does not give a bias pressure across the enclosure boundary or otherwise preclude accurate testing, and which would be shut down on extinguishant discharge, may be left operating during the test if this is needed to avoid temperature build-up in equipment such as computers; and
b) air-handling equipment, with fresh air makeup or exhaust, which would continue to operate on extinguishant discharge should be shut down as it can create excessive bias pressure during the integrity test.

F-2.7.1.5 Post the appropriate signs on doors (*see* **F-2.2.6**).

F-2.7.1.6 Open doors and remove floor or ceiling tiles within the extinguishant-protected portions of the enclosure envelope so that the extinguishant-protected volume is treated as one space. Do not remove false ceiling tiles if the volume above the false ceiling is not protected with extinguishant.

NOTE — The removal of raised floor tiles creates a serious safety hazard. Appropriate precautions should be taken.

F-2.7.1.7 Set all doors and windows and other openings in the enclosure envelope to the state they would be during the hold time.

F-2.7.1.8 Check that liquid traps in the floor and sink drains are sealed with liquid.

F-2.7.1.9 Record the conditions (enclosure, surroundings and services) during the fan test.

F-2.7.2 *Setting up the Door Fan Unit*

F-2.7.2.1 Set up the fan unit in an access opening leading from the enclosure into the largest volume of building space which will complete the airflow path from the fan, via the enclosure, leaks, and building space back to the fan.

F-2.7.2.2 Gently blow into or suck from, the flexible tubing so that the readings of the pressure measuring devices traverse the full scale. Hold the maximum reading for not less than 10 s.

Release the pressure and zero the devices.

F-2.7.2.3 Connect the enclosure differential pressure measuring device and the fan pressure measuring device. Ensure that the open ends of the flexible tubing near the fan unit are away from its air stream path and any other air flows which might affect the readings.

F-2.7.2.4 Use the fan(s) to raise or lower the pressure of the enclosure to the maximum safe pressure obtainable. Check all dampers with smoke and ensure that they are closed properly. Check doors and hatches and ensure correct closure. Inspect the wall perimeter (above and below any false floor) and the floor slab for any major leaks and note their size and location.

F-2.7.2.5 Ensure that there will be no pressure differential between the area of the fan outside the enclosure and along the return air paths around the boundary of the enclosure under test. This may be done visually or by pressure measurement.

F-2.7.3 *Measurement of Bias Pressure During Fan Testing (P_{bt})*

F-2.7.3.1 P_{bt} is used to correct the measured inside-outside enclosure pressure differential to calculate the enclosure leakage characteristics.

F-2.7.3.2 Seal the fan unit and, without the fan(s) operating, allow the enclosure differential pressure reading to stabilize if possible (which can take up to 30 s) and record the pressure differential, P_{bt}, and its direction. Take P_{bt} as positive if the inside pressure is above the outside pressure, and negative if the inside pressure is below the outside pressure. If the magnitude of P_{bt} is greater than 3 Pa (that is $|P_{bt}| > 3$ Pa), it should be reduced before proceeding with the integrity test.

F-2.7.3.3 Make every effort to reduce the static pressure, P_{bt}, by shutting down air handling equipment even though it can operate during the hold time.

If a subfloor pressurization air-handler cannot be shut down for the test and leaks exist in the subfloor, these leaks cannot be accurately measured. During the test, as many floor tiles as necessary should be lifted to eliminate the effect of subfloor pressurization, or every effort should be made to reduce subfloor leaks to insignificance.

NOTE — The removal of raised floor tiles creates a serious safety hazard. Appropriate precautions should be taken.

F-2.7.3.4 If P_{bt} fluctuates (for example due to wind effects), it is unlikely to achieve the necessary correlation accuracy in the fan test results. The fluctuations need to be reduced, before accurate fan tests can be carried out, by sealing leakage paths between the enclosure and the source of fluctuating pressure.

F-2.7.4 *Measurement of Leakage Rate*

F-2.7.4.1 Measure the air temperature inside the enclosure, T_e, and measure the air temperature outside the enclosure, T_o, at several points. If the location of leaks is not known, use the average value; otherwise, use the average value weighted according to the known location of the leaks. Verify the temperatures at the end of the test.

F-2.7.4.2 Unseal the fan inlet or outlet and connect the fan flow pressure measuring device.

F-2.7.4.3 Use the fan unit to depressurize the enclosure to the maximum extent, but preferably by not more than 60 Pa, as at higher differential pressures the flow characteristics of the leak paths can change. Allow the enclosure differential pressure reading to stabilize (which can take up to 30 s) and record the pressure differential that is ($P_f + P_{bt}$) which will be negative. Repeat at not less than four more fan unit flow rates to give five readings more or less evenly spaced over the range down to 10 Pa or 10 $|P_{bt}|$ whichever is the higher. At each pressure difference, measure the airflow and pressure difference across the enclosure/fan boundary. After the fan and instrumentation have stabilized, the average over an interval equal to, or greater than, 10 s should be used if fluctuations are observed. If stable readings cannot be obtained at the minimum pressure difference (10 Pa or 10 $|P_{bt}|$) then only go down to the lowest pressure at which stable readings can be obtained.

F-2.7.4.4 Use the fan unit to pressurize the enclosure and repeat the procedure of **F-2.7.4.3**. Again, record values of ($P_f + P_{bt}$), which will be positive.

F-2.7.4.5 Repeat the zero-flow pressure difference (bias pressure P_{bt}) measurement. If the reading differs from the initial zero flow pressure difference reading by more than 1 Pa, repeat the test.

F-2.7.5 *Field Calibration Check*

F-2.7.5.1 Calculate the enclosure's equivalent leakage area (average of pressurization and depressurization), at a reference pressure differential of 10 Pa, using **Formula (27)** (*see* **F-3.2**).

F-2.7.5.2 In a sheet of a rigid material, less than 3 mm thick and free of any penetrations, cut a sharp- edged circular calibration check orifice. The area of the orifice shall be large enough to cause an easily measurable increase in the enclosure's leakage rate, but not so large that a different range of the fan unit shall be used to measure the increased flow. A geometrical area of about 50 percent of the enclosure's equivalent leakage area is likely to be suitable. Install the sheet in an unused fan unit port if possible. Otherwise, install the sheet in some other convenient enclosure opening but consider that this will modify the enclosure's leakage characteristic and reduce the accuracy of the field calibration check.

F-2.7.5.3 Seal the fan unit and orifice, repeat the measurement of bias pressure during fan testing (*see* **F-2.7.3**) and record the value of P_{bt}.

Open the calibration check orifice and repeat the measurement of leakage rate (*see* **F-2.7.4**).

F-2.7.5.4 Calculate the equivalent leakage area (average of pressurization and depressurization) of the enclosure with the orifice at reference pressure differential (10 Pa).

F-2.7.5.5 The measured equivalent leakage area of the calibration orifice is the equivalent leakage area of the enclosure with the orifice minus the equivalent leakage area of the enclosure alone.

F-2.7.5.6 The field calibration check is acceptable if the measured equivalent leakage area of the orifice is within ± 15 percent of its geometrical area. If the difference is greater than 15 percent, the fan unit should be recalibrated.

F-2.7.6 *Measurement of Bias Pressure under Hold Time Conditions (P_{bt})*

F-2.7.6.1 P_{bh} is the bias pressure under hold time conditions that are used in the calculation of the hold time.

F-2.7.6.2 Set the enclosure, its surroundings, and services, to the conditions that would apply during the hold time using the information from **F-2.5**.

F-2.7.6.3 Seal the fan unit and, without the fan(s) operating, connect a manometer to measure the pressure differential, P_{bh}, and its direction. Measure between a single fixed reference point inside the enclosure, and:

a) a point immediately outside the upper leakage, and
b) a point immediately outside the lower leakage.

Allow the enclosure differential pressure reading to stabilize if possible (which can take up to 30 s) and record the pressure differential, P_{bh}, and its direction for both positions. Take P_{bh} as positive if the inside pressure is above the outside pressure, and negative if the inside pressure is below the outside pressure.

If the enclosure is large, repeat the pairs of measurements at several points to determine the average value of P_{bh}, but note that if P_{bh} varies significantly from place to place then it can cause non-uniform flow through leakage areas, invalidating the hold time equation.

The value of P_{bh} for hold time calculations is given by:

a) for extinguishants heavier than air ($\rho_a < \rho_e$), $P_{bh} = P_{bh}(\text{lower}) - P_{bh}(\text{upper})$
b) for extinguishants lighter than air ($\rho_a > \rho_e$), $P_{bh} = P_{bh}(\text{upper}) - P_{bh}(\text{lower})$

The tubing used to connect the manometer to the points outside the upper and lower leakages should be filled with air at ambient temperature, so that the measured value of P_{bh} will not be affected by gravity acting on the air between the upper and lower leakage.

F-2.7.6.4 If P_{bh} fluctuates (for example due to wind effects), the predicted hold time will be uncertain. In this case, use the most negative value of P_{bh} when checking whether flow reversal will occur (*see* **F-2.8.4**) and the most positive value when calculating the predicted hold time (*see* **F-2.8.6**, **F-2.8.7**, **F-2.8.8** and **F-2.8.9**).

F-2.7.6.5 If the bias pressure P_{bh} has a numerical value greater than 25 percent of the initial extinguishant/ air column pressure [*see* **Formula (6)** in **F-2.8.4**], that is $|P_{bh}| > 0.25\ P_{mi}$ then the hold time is likely to be low and the enclosure will not hold the specified extinguishant concentration. The source of the excessive bias pressure should be identified (and traced using inert smoke) and if possible, permanently reduced. If it cannot be permanently reduced it shall be recognized that the hold time can be adversely affected.

F-2.8 Calculation

F-2.8.1 *Selection of Appropriate Hold Time Equation*

For enclosures without continuous mixing, the standard enclosure hold time equation is easier to solve than the non-standard enclosure equation. In certain circumstances, it may be acceptable to use the standard enclosure equation to calculate the hold time for a non-standard enclosure, although the non- standard enclosure equation will be more accurate.

For enclosures where the horizontal cross-sectional area decreases from the top of the enclosure to the bottom (for example a ship's hull or a flat-topped and vertical walled room with a cable trench), the standard enclosure equation will underestimate the hold time (in the upper part of the enclosure) for extinguishants heavier than air and overestimate it (in the lower part) for extinguishants lighter than air.

For enclosures where the horizontal cross-sectional area increases from the top of the enclosure to the bottom (for example enclosures with pitched roofs), the standard enclosure equation will overestimate the hold time (in the upper part) for extinguishants heavier than air and underestimate it (in the lower part) for extinguishants lighter than air.

It is important to use the non-standard enclosure equation when the standard enclosure equation will overestimate the hold time because the standard enclosure equation can predict a pass for an enclosure that would fail.

It is less important to use the non-standard enclosure equation when the standard enclosure equation will underestimate the hold time, although the standard enclosure equation can predict a failure for an enclosure that would pass.

Expert advice should be sought in case of doubt.

F-2.8.2 *Symbols*

The symbols of the quantities, and their units, used in the calculation are given in Table 12.

Table 12 Symbols, Quantities and Units
(*Clause* F-2.8.2)

Sl No.	Symbol	Quantity	Unit
(1)	(2)	(3)	(4)
i)	A	horizontal cross-sectional area at height H	m^2
ii)	A_e	effective leakage area	m^2
iii)	C	extinguishant concentration at height h	percent vol.
iv)	c_i	initial concentration of extinguishant in the air for the enclosure at the beginning of the hold time	percent vol.

Sl No.	Symbol	Quantity	Unit
(1)	(2)	(3)	(4)
v)	c_{min}	minimum concentration of extinguishant in the air at height *H* in the enclosure at the end of the hold time — not less than the extinguishing concentration	percent vol.
vi)	E_A	equivalent leakage area	m^2
vii)	E_P	leakage opening area	m^2
viii)	*F*	lower leakage fraction, effective leakage area of lower leaks divided by effective leakage area of all leaks	dimensionless
ix)	g_n	acceleration due to gravity	m/s^2
x)	*H*	height from the lowest point in the enclosure	m
xi)	H_e	height of the equivalent sharp interface	m
xii)	H_o	overall height of the enclosure	m
xiii)	H_p	required protected height — required height of c_{min} at the end of the hold time	m
xiv)	I_t	interface thickness constant [*see* **Formula (7)** and table for values for each agent]	m
xv)	I_p	Interface position constant [*see* **Formula (7)** and table for values for each agent]	dimensionless
xvi)	k_0	leakage characteristic [*see* **Formula (1)**]	$m^3/(s.Pan)$
xvii)	k_1	leakage characteristic [*see* **Formula (11)**]	m3/(s.Pan)
xviii)	k_2	correlation constant [*see* **Formula (14)**]	$[kg^n m^{3(1-n)}]/(s.Pan)$
xix)	k_3	simplifying constant [*see* **Formula (15)**]	m/s^2
xx)	k_4	simplifying constant [*see* **Formula (16)**]	$Pa.m^3/kg$
xxi)	*N*	leakage characteristic [*see* **Formula (11)**]	1
xxii)	P_{bh}	bias pressure during the hold time	Pa
xxiii)	P_{bt}	bias pressure at the time of the fan test	Pa
xxiv)	P_c	atmospheric pressure during fan calibration	bar[a]
xxv)	P_f	differential pressure produced by the fan	Pa
xxvi)	P_{mi}	initial extinguishant/air column pressure	Pa
xxvii)	P_{mf}	final extinguishant/air column pressure	Pa
xxviii)	P_{ref}	reference pressure difference for equivalent leakage area	Pa
xxix)	P_t	atmospheric pressure at the time of fan test	bar[a]

Sl No.	**Symbol**	**Quantity**	**Unit**
(1)	(2)	(3)	(4)
xxx)	Q	volume flow rate in through the upper leaks and out through the lower leaks	m^3/s
xxxi)	Q_f	measured airflow rate through the fan	m^3/s
xxxii)	Q_l	airflow rate, temperature and pressure corrected to reference conditions (20 °C, 1,013 bara atmospheric pressure)	m^3/s
xxxiii)	Q_{ref}	enclosure air leakage rate at pressure difference *P*ref	m^3/s
xxxiv)	r or r_2	correlation coefficient	
xxxv)	T	predicted hold time [*see* **Formulae (17)** to **(20)**]	s
xxxvi)	T_c	atmospheric temperature during calibration of the fan unit	°C
xxxvii)	T_e	air temperature inside the enclosure	°C
xxxviii)	T_o	air temperature outside the enclosure	°C
xxxix)	V	enclosure net volume	m^3
xl)	V_e	volume of extinguishant in the enclosure [*see* **Formula (21)**]	m^3
xli)	V_{ef}	final value of V_e	m^3
xlii)	V_{ei}	initial value of V_e	m^3
xliii)	ρ_a	air density (1.205 at 20 °C and 1.013 bara)	kg/m^3
xliv)	ρ_e	extinguishant density at 20 °C and 1.013 bara atmospheric pressure	kg/m^3
xlv)	ρ_m	extinguishant/air mixture density at 20 °C and 1.013 bara atmospheric pressure	kg/m^3
xlvi)	ρ_{mf}	extinguishant/air mixture density at the concentration c_{min} 20 °C and 1.013 bar[a] atmospheric pressure	kg/m^3
xlvii)	ρ_{mi}	extinguishant/air mixture density at initial concentration c_i, 20 °C and 1.013 bara atmospheric pressure	kg/m^3

[a] 1 bar = 0.1 MPa = 10^5 Pa; 1 MPa = 1 N/mm^2.

F-2.8.3 *Depressurization and Pressurization Leakage Characteristics*

From the measured values of (P_f + P_{bt}) and P_{bt}, calculate the values of P_f and, using the fan calibration data (*see* **F-2.3.1**), the corresponding airflow rates Q_f through the fan.

For each set of results (pressurization and depressurization), express the fan test results in the form:

$$|Q_f| = k_o \, |P_f|^{\,n} \quad \ldots(1)$$

Determine k_o, n, and the correlation coefficient (r or r_2) using ordinary least squares regression to fit: $\ln|Q_f| = \ln k_o + n \ln|P_f|$ to the data. Check that the correlation coefficient of each set is not less than r = 0.99 or r^2 = 0.98. The two sets will almost always have different values of k_o and n.

If the correlation coefficient is too low:

a) repeat the test,
b) check for fluctuating bias pressure, and
c) check for damper/vent movement during the test.

Calculate the corrected values of k_o using **Formulae (2)** and **(3)**, as appropriate, and call them k_1. For depressurization:

$$k_1 = k_o \left(\frac{P_c\,(T_e+273)}{P_t\,(T_c+273)}\right)^{1/2} \left(\frac{T_o+273}{T_e+273}\right) \left(\frac{P_t(\,20+273\,)}{1.013(\,T_o+273)}\right)^{n} \quad \ldots(2)$$

For Pressurization:

$$k_1 = k_0 \left(\frac{P_c\,(T_o+273)}{P_t\,(T_c+273)}\right)^{1/2} \left(\frac{T_e+273}{T_o+273}\right) \left(\frac{P_t(\,20+273\,)}{1.013(\,T_e+273)}\right)^{n} \quad \ldots(3)$$

NOTE — **Formulae (2)** and **(3)** correct the flow rates for the effects of temperature and pressure differences on air density, assuming that:

a) the flowmeter is of the usual type that gives a pressure signal proportional to the air density and the square of the volume flow rate, and
b) for a given inside-outside pressure difference, the volume flow rate through the enclosure leakage is inversely proportional to the air density to the power n.

The correction is approximate as the second assumption is an approximation, and the effects of humidity and viscosity are ignored.

F-2.8.4 *Column Pressures*

Calculate the density of the extinguishant/air mixture at 20 °C at the initial concentration using **Formula (4)**:

$$\rho_{mi} = \rho_e \frac{c_i}{100} + \rho_a \frac{100 - c_i}{100} \quad \ldots(4)$$

For enclosures with continuous mixing, calculate the density of the extinguishant/air mixture at 20 °C at the concentration, c_{min}, using **Formula (5)**:

$$\rho_{mf} = \rho_e \frac{C_{min}}{100} + \rho_a \frac{100 - C_{min}}{100} \quad \ldots(5)$$

Calculate the initial extinguishant/air mixture column pressure, P_{mi}, using **Formula (6)**:

$$P_{mi} = g_n H_o \,|\rho_{mi} - \rho_a| \quad \ldots(6)$$

For enclosures without continuous mixing, if *c*min is less than 0.5 *c*i then take the equivalent sharp interface height H_e as equal to *H*. Otherwise, calculate H_e as follows:

$$H_e = H + I_t \left(\frac{c_{min}}{c_{i\,(p)}} - I_p\right) \qquad ...(7)$$

If $H_e \geq H_o - I_p{*}I_t$ then the interface has not fully developed and **Formula (8)** should be used

$$H_e = H_o - (H_o - H)\frac{I_p c_i}{c_{min}} \qquad ...(8)$$

For extinguishants heavier than air and $c_{min} \geq 0.5c_i$, the value of H_e shall be in the range 0.5 $H_o \leq H_e \leq H_o$. If this is not the case, the Formulae for H_e and hold time are not valid (as there will be no extinguishant/ air mixture at the initial concentration remaining in the enclosure).

For all enclosures, calculate the final extinguishant/air mixture column pressure, P_{mf}.

For all extinguishants in enclosures without continuous mixing, **Formula (9)** applies:

$$P_{mf} = g_n H_e |\rho_{mi} - \rho_a| \qquad ...(9)$$

For all extinguishants in enclosures with continuous mixing, **Formula (10)** applies:

$$P_{mf} = g_n H_e |\rho_{mf} - \rho_a| \qquad ...(10)$$

For all enclosures, if P_{bh} is negative, check that P_{mf} is greater than the absolute value of P_{bh}. If this is not the case, the hold time equations are not valid (as bias pressure will cause flow reversal).

The values for the interface thickness, I_t, and the interface position, I_p, are shown in Table 13.

Table 13 Values for the Interface Thickness, I_t, and the Interface Position, I_p
(*Clause* F-2.8.4)

Sl No.	Agents	I_p	I_t
(1)	(2)	(3)	(4)
i)	Inert agents	0.63	1.30
ii)	Carbon dioxide	0.63	1.30
iii)	FK-5-1-12	0.52	0.45
iv)	HFC-227ea	0.68	0.80
v)	HFC-125	0.61	1.10
vi)	HFC-23	0.58	0.85
vii)	Other HC	0.52	1.10
viii)	IG-100	n/a	n/a

F-2.8.5 *Average Leakage Characteristics*

Determine the average values of the leakage characteristics k_1 and n, as follows [**Formulae (11)** and **(12)**].

Calculate the average values (that is of the pressurization and depressurization data) of $Q_l = k_1 |Pf|n$ for values of P_f equal to P_{mi}, and P_f equal to 0.5 P_{mi}. These are Q_{lm} and $Q_{lm/2}$ respectively:

$$n = \frac{lnQ_{lm} - lnQ_{lm/2}}{ln2} \qquad \text{...(11)}$$

$$k_1 = exp\left(\frac{(lnQ_{lm/2})(ln\,P_{mi} - ln\,Q_{lm})\,(ln\,P_{mi} - ln2)}{ln2}\right) \qquad \text{...(12)}$$

If the leakage opening area has been recorded under **F-2.6.4** then, for subsequent calculations, k_1 should be multiplied by using **Formula (13)**:

$$\frac{E_A + E_P}{E_A} \qquad \text{...(13)}$$

where E_A is the measured E_A of the enclosure from **F-2.7** using **Formula (28)** and leakage opening area is determined according to **F-2.6.4**.

F-2.8.6 *Correlation and Simplifying Constants*

Calculate the correlation constant k_2 using **Formula (14)**:

$$k_2 = k_1 \left(\frac{\rho_a}{2}\right)^n \qquad \text{...(14)}$$

Calculate the simplifying constant k_3 using **Formula (15)**:

$$k_3 = \frac{2g_n|\rho_{mi} - \rho_a|}{\rho_{mi} + \rho_a\left(\frac{F}{1-F}\right)^{1/n}} \qquad \text{...(15)}$$

Calculate the simplifying constant k_4 using **Formula (16)**:

For extinguishants heavier than air ($\rho_a < \rho_e$)

$$k_4 = \frac{2P_{bh}}{\rho_{mi} + \rho_a\left(\frac{F}{1-F}\right)^{1/n}} \qquad \text{...(16)}$$

F-2.8.7 *Predicted Hold Time: Standard Enclosures without Continuous Mixing*

For standard enclosures without continuous mixing, the predicted hold time, t, for the extinguishant concentration at height, H, to fall from the concentration, c_i to c_{min}, may be calculated by assuming the extinguishant distribution in the enclosure, and calculating the hold time for an equivalent sharp

interface which would give the same column pressure and rate of loss of extinguishant as the actual extinguishant distribution.

In this calculation procedure, it is assumed that the enclosure is standard.

For extinguishants heavier than air, the extinguishant concentration at any particular instant equals the initial concentration, c_i, from the lower boundary of the enclosure up to a certain height, and above this decreases linearly with increasing height to zero at the upper boundary of the enclosure or the interface thickness, whichever is the lesser.

Assume F = 0.5 and calculate the predicted hold time, t, using **Formula (17)**:

$$t = \frac{V}{H_o}\left(\frac{(k_3 H_o + k_4)^{1-n} - (k_3 H_e + k_4)^{1-n}}{(1-n)k_2 F k_3}\right) \qquad \text{...(17)}$$

F-2.8.8 *Predicted Hold Time: Enclosures of Any Shape with Continuous Mixing*

For enclosures of any shape with continuous mixing, assume F = 0.5 and calculate the predicted hold time, t, for the extinguishant concentration in the enclosure to fall from the initial concentration, c_i, to the concentration, c_{min} (*see* **7.8**), using **Formula (18)** and **(19)**:

For extinguishants heavier than air ($\rho_a < \rho_e$):

$$t = \frac{V}{Fk_2}\int_{P_{mf}}^{P_{mi}} \left(\frac{2g_n H_o (\rho_m - \rho_a)^{(n+1)/n} + 2P_{bh}(\rho_m - \rho_a)^{1/n}}{\rho_m + \rho_a\left(\frac{F}{1-F}\right)^{1/n}}\right)^{-n} d\rho_m \qquad \text{...(18)}$$

For extinguishants lighter than air ($\rho_a > \rho_e$):

$$t = \frac{V}{(1-F)k_2}\int_{\rho_{mi}}^{\rho_{mf}} \left(\frac{2g_n H_o (\rho_a - \rho_m)^{(n+1)/n} + 2P_{bh}(\rho_a - \rho_m)^{1/n}}{\rho_m + \rho_a\left(\frac{1-F}{F}\right)^{1/n}}\right)^{-n} d\rho_m \qquad \text{...(19)}$$

Solve the equation by a method of approximation, for example, by using Simpson's Rule using an even number (not less than 20) of intervals.

F-2.8.9 *Predicted Hold Time for Non-Standard Enclosures without Continuous Mixing*

F-2.8.9.1 Determine the variation of the horizontal cross-sectional area of the enclosure with height.

F-2.8.9.2 In this calculation procedure, it is assumed, for extinguishants heavier than air, the extinguishant concentration at any particular instance equals the initial concentration, c_i, from the lower boundary of the enclosure up to a certain height, and above this decreases linearly with increasing height to zero at the upper boundary of the enclosure, or the interface thickness, whichever is lesser.

F-2.8.9.3 Assume F = 0.5 and solve **Formula (20)** by an analytical or numerical method to calculate the predicted hold time, t:

$$t = \frac{100}{c_i}\int_{V_{ei}}^{V_{ef}} \frac{1}{Q}\, dV_e \qquad \text{...(20)}$$

with the aid of the following substitutions [**Formulae (21)** to **(24)**]:

$$V_e = \int_0^{H_o} \frac{ac}{100}\, dh \qquad \text{...(21)}$$

$$dV_e = \frac{ac}{100}\,dh \qquad \ldots(22)$$

NOTE — '*a*' depends upon '*h*'; '*c*' depends upon '*h*' and the interface height.

$$P_m = g_n|\rho_e - \rho_a| \int_0^{H_o} \frac{c}{100}\,dh \qquad \ldots(23)$$

$$Q = (1-F)k_2 \left(\frac{2P_m + 2P_{bh}}{\rho_{mi} + \rho_a \left(\frac{1-F}{F}\right)^{1/n}} \right)^n \qquad \ldots(24)$$

An approximate value of the hold time can be found by making a simplifying assumption when solving **Formula (20)**. This approximate value will be shorter than or equal to an accurate solution. To obtain the approximate value of hold time, assume P_m is fixed at its initial value (when $c = c_i$ throughout the enclosure) and calculate the resulting value of *Q*. Inserting this fixed value of *Q* in **Formula (20)** gives **Formula (25)**:

$$t = 100\left(\frac{V_{ei} - V_{ef}}{c_i Q}\right) \qquad \ldots(25)$$

F-3 TREATMENT OF ENCLOSURES WITH PREDICTED HOLD TIMES LESS THAN THE RECOMMENDED VALUE

F-3.1 General

If the predicted hold time, calculated in accordance with **F-2**, is less than as recommended in **10.2.10** (c) (iii), then **F-3.2** to **F-3.4** may be implemented as necessary for agents heavier than air.

F-3.2 Leakage Areas

To quantify the scale of the problem, calculate the effective leakage area, A_e, from **Formula (26)**:

$$A_e = Q_{ref}\left(\frac{\rho_a}{2P}\right)^{1/2} = k_1 P_{ref}^{n-0.5}\left(\frac{\rho_a}{2}\right)^{1/2} \qquad \ldots(26)$$

At 20 °C and 1.013 bar, **Formula (26)** reduces to **Formula (27)**:

$$A_e = 0.776 k_1 P_{ref}^{n-0.5} \qquad \ldots(27)$$

The equivalent leakage area, E_A, can be calculated using **Formula (28)**:

$$E_A = \frac{A_e}{0.61} \qquad \ldots(28)$$

The equivalent leakage area is used for fan calibration checks and identification of actual leaks. It is the area of a circular sharp-edged orifice that has the same value of A_e as the actual leakage area at the reference pressure differential.

F-3.3 Improved Sealing of the Enclosure

Consideration should be given to improving the sealing of the enclosure. If the sealing is improved and the new predicted hold time, after new fan test measurements in accordance with **F-2.7.4**, is not less than the minimum recommended value, no further action is necessary.

F-3.4 Quantification and Location of Leaks

F-3.4.1 *General*

For extinguishants heavier than air, the extinguishant/air mixture will escape through the lower leaks and air will flow in through the upper leaks. In an enclosure without bias pressure, the "neutral plane" (between inflow and outflow) can be taken as the mid-height of the enclosure. For this assessment, lower leaks are assumed to be those below the neutral plane, and upper leaks are those above it.

The fan test does not show the location of the leaks or the value of the lower leakage fraction, *F*. In **F-2.8.7** to **F-2.8.9**, it is assumed that the value of *F* is 0.5, all the lower leaks are in the base of the enclosure and all the upper leaks are in the top of the enclosure. This is the worst case and gives the minimum value for hold time.

If some lower leaks are above the base of the enclosure or if some upper leaks are below the top of the enclosure, the hold time will be underestimated but a simple mathematical treatment of this case is not possible.

The hold time will also be underestimated if *F* is not 0.5 and the effect of this can be calculated.

F-3.4.2 *A Second Calculation of Hold Time*

Make a second calculation of the hold time, *t*, assuming *F* = 0.15. If this value is more than the recommended minimum [*see* **10.2.10** (c) (iii)] then determine by test the actual value of *F* using the method described in **F-3.4.3**.

F-3.4.3 *Method of Estimating F*

F-3.4.3.1 *quantification of lower leaks*

Temporarily isolate identifiable upper leaks with sheet material and/or a neutralizing pressure. Repeat the fan test and calculate the reduced equivalent leakage area E_{A2} using **Formulae (28)** to **(30)**. E_{A2} will comprise lower leaks and unsealed or un-neutralized upper leaks. The equivalent leakage area of the sealed or neutralized upper leaks will be ($E_A - E_{A2}$).

If $E_{A2} \geq 0.5\ E_A$, proceed to **F-3.4.3.2**.

If $E_{A2} < 0.5\ E_A$, calculate the new value of *F* using **Formula (29)**:

$$F = \frac{E_{A2}}{E_A} \qquad \ldots(29)$$

and calculate the new predicted hold time in accordance with **F-3.4.4**.

If the new predicted hold time is not less than the minimum recommended value, no further action is necessary. Otherwise, proceed to **F-3.4.3.2**.

F-3.4.3.2 *quantification of upper leaks*

Unseal the upper leaks and temporarily isolate identifiable lower leaks with sheet material and/or a neutralizing pressure. Repeat the fan test and calculate the reduced equivalent leakage area, E_{A3}, using **Formulae (26)** to **(28)**. E_{A3} will comprise upper leaks and unsealed or un-neutralized lower leaks. The equivalent leakage area of the sealed or neutralized lower leaks will be ($E_A - E_{A3}$).

Having thus quantified the temporarily sealed or neutralized upper and lower leaks, treating the remaining equivalent leakage area as 50 percent upper leaks and 50 percent lower leaks leads to **Formula (30)**. Calculate the new value of *F* using **Formula (30)**:

$$F = 0.5\frac{E_A + E_{A2} - E_{A3}}{E_A} \qquad \ldots(30)$$

and calculate the new predicted hold time in accordance with **F-3.4.4**. If this is not less than the minimum recommended value, no further action is necessary.

F-3.4.4 *Final Calculation of Hold Time*

Using the value of *F* determined as in **F-3.4.3**, recalculate the hold time, *t*. *F* should not be more than 0.5 or less than 0.15. If *F* is less than 0.15, use *F* = 0.15. If *F* is greater than 0.5, use *F* = 0.50.

If the predicted hold time, calculated in accordance with **F-2**, is less than as recommended in **10.2.10** (c) (iii), improve the sealing of the enclosure in accordance with **F-3.3**.

Extreme values of *F*, close to 0 or 1, can yield unrealistically long predicted hold times. If the lower (outlet) leakage area is large then airflow in, as well as the mixture flow out, can occur at the outlet — invalidating the hold time equations.

Values of *F* other than 0.5 may only be used when determined by the test and whose results are recorded in the fan test report.

F-4 REPORT

Prepare a written report containing the following information:

a) Enclosure leak flow characteristics (that is the average values of k_1 and *n*).
b) Initial concentration of extinguishant, minimum concentration, and the extinguishant to be used.
c) Quantity of extinguishant provided.
d) Net volume of the enclosure.
e) Height of the enclosure and, for a non-standard enclosure, the appropriate dimensions.
f) For an enclosure without continuous mixing, the required protected height.

g) Predicted hold time and whether or not the value conforms to the recommendation of **10.2.10** (c) (iii), that is whether it is less than 10 min or the higher necessary value, as appropriate.

h) Information on the arrangement and status of the enclosure, surroundings and services as specified in **F-2.5** and **F-2.7.1.4**.

j) Current calibration data for the fan unit and the pressure measuring devices, corresponding certificates if available, and the results of the field calibration check.

k) Test results, including a record of the test measurements and any appropriate calculations.

m) Size and location of leaks if identified. ’

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(CED 22)