DRAFT ISPM: *REQUIREMENTS FOR THE USE OF FUMIGATION AS A PHYTOSANITARY MEASURE* (2014-004)

Status box

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Adoption

[Text to this paragraph will be added following adoption.]

INTRODUCTION

Scope

This standard provides technical guidance for national plant protection organizations (NPPOs) on the application of fumigation as a phytosanitary measure, encompassing treatments with chemicals that reach the commodity in a gaseous state. This standard also provides guidance for NPPOs on the authorization of entities to conduct fumigation.

This standard does not provide details on treatments with specific fumigants. Application of modified atmosphere as a phytosanitary treatment is not part of this standard.

References

The present standard refers to ISPMs. ISPMs are available on the International Phytosanitary Portal (IPP) at https://www.ippc.int/core-activities/standards-setting/ispms.

CPM R-03. 2017. Replacement or reduction of the use of methyl bromide as a phytosanitary measure. CPM Recommendation. Rome, IPPC, FAO. Available at https://www.ippc.int/en/publications/84230/ (last accessed 3 June 2018).

Definitions

Definitions of phytosanitary terms used in this standard can be found in ISPM 5 (*Glossary of phytosanitary terms*).

Outline of Requirements

NPPOs should ensure that the fumigation application is carried out effectively so that critical parameters are at the required level throughout the commodity to achieve the stated efficacy.

The main requirements for the application of fumigation, the use of equipment, and the fumigation procedures should be followed. Systems should be implemented to prevent the infestation or contamination of the fumigated commodity. Record keeping and documentation requirements should be followed to enable auditing, verification or trace-back.

The roles and responsibilities of parties involved in fumigation are described. Guidance is provided to NPPOs on authorizing, monitoring and auditing treatment entities.

BACKGROUND

The purpose of this standard is to provide generic requirements for the application of fumigation as a phytosanitary treatment, specifically for those treatments adopted under ISPM 28 (*Phytosanitary treatments for regulated pests*).

ISPM 28 was adopted to harmonize effective phytosanitary treatments over a wide range of circumstances and to enhance the mutual recognition of treatment efficacy by NPPOs, which may facilitate trade. ISPM 28 provides requirements for submission and evaluation of efficacy data and other relevant information on phytosanitary treatments, and annexes with specific fumigations that have been evaluated and adopted by the Commission on Phytosanitary Measures.

Fumigation is considered to be effective when the specific concentration of fumigant at the minimum temperature and duration required for the stated efficacy is achieved.

IMPACTS ON BIODIVERSITY AND THE ENVIRONMENT

Historically, fumigation has been widely applied to prevent the introduction and spread of regulated pests and has, therefore, been beneficial to biodiversity. However, fumigant gases, such as methyl bromide, sulphuryl fluoride, phosphine and ethyl formate, may have negative impacts on the environment. For example, the emission of methyl bromide into the atmosphere is known to deplete the ozone layer and sulphuryl fluoride is a recognized greenhouse gas. The IPPC Recommendation on the replacement or reduction of the use of methyl bromide as a phytosanitary measure (CPM R-03, 2017) has been adopted in relation to this issue. It encourages contracting parties to choose other fumigants, where possible. Environmental impacts of fumigants can be mitigated through the use of destruction (chemical breakdown) or recapture technology to reduce gas emissions.

REQUIREMENTS

1. Fumigation Objective

The objective of using fumigation as a phytosanitary measure is to achieve pest mortality at a specified efficacy.

2. Fumigation Application

Fumigation is undertaken by treatment providers (e.g. fumigation companies or individuals) either in a treatment facility or at other locations (e.g. cargo ship holds and warehouses).

Fumigation may be applied at any point along the supply chain, for example:

- as an integral part of production or packaging operations
- after packaging (e.g. once the commodity is packaged for dispatch)
- during storage
- just before dispatch (e.g. at centralized locations at a port)
- during transport
- upon arrival in the importing country (before or after unloading).

The requirement of fumigation is to ensure that the critical parameters (e.g. concentration or dose, temperature, duration) are at the required level throughout the commodity, allowing the stated efficacy to be achieved.

Fumigation efficacy may be affected by factors such as the moisture content of the commodity and, within the enclosure used for the fumigation, the humidity, pressure, and changes in the atmospheric gas composition created by the packaging or by the commodity. Other factors to consider during fumigation are the penetration of the fumigant, sorption of the fumigant by the packaging or the commodity, and circulation of the fumigant. For circulation of fumigants, NPPOs should take into account differences in the loading configuration between the commodity loaded in boxes with spacing and the commodity loaded in bulk.

The procedures approved by the NPPO for the application of a treatment should be clearly described in a “treatment protocol”. These procedures should be designed to ensure that the critical parameters stated in the treatment schedule are achieved. The procedures should include the process of pre- and post-conditioning to reach the required dose, where these processes are critical to the treatment achieving the required efficacy while preserving commodity quality. They should also include contingency procedures and guidance on corrective actions for treatment failures or problems with critical treatment parameters.

Some fumigants react with certain commodities or materials and this needs to be taken into consideration before fumigation (e.g. phosphine reacts strongly with copper and may affect electronics).

4. Ways of Applying Fumigation

The following are the main ways that fumigation is applied.

4.1 Single fumigant treatments

The most common fumigations used are those that apply a single fumigant. General-use fumigants such as phosphine or sulphuryl fluoride rely on a mode of action that is generally effective against all pest groups or against one particular group (e.g. arthropods, fungi, nematodes) and all or most life stages. Treatment schedules for single fumigants are generally simple, requiring a single application to achieve a required minimum concentration over a required duration to achieve the specified efficacy. A list of commonly used fumigants and their chemical properties is provided in Appendix 1.

4.2 Combination treatments

Where a single fumigant may not achieve the required efficacy without rendering the commodity unmarketable, or for reasons of economy or logistics, another fumigant or treatment may be included in the treatment schedule.

Another treatment may be applied sequentially immediately before or after fumigation to increase the effectiveness of the combination treatment. For example, fumigant and temperature treatments applied sequentially may be necessary where the commodity is vulnerable to damage from the increased severity required of either treatment alone, or where the most tolerant life stage of the target pest is different for the different treatments.

Concurrent combinations of a fumigant with other fumigants or other type of treatments may also be beneficial in terms of effectiveness, commodity tolerance, economics or logistics, compared to treatment with a single fumigant alone.

4.3 Fumigation under special conditions

Fumigation may be conducted under special conditions to increase efficacy.

4.3.1 Fumigation under modified atmosphere

Increasing the atmospheric carbon dioxide concentration in the enclosure used for fumigation, either alone or in combination with increasing the nitrogen and decreasing or increasing the atmospheric oxygen concentrations, may be used to increase the efficacy of the fumigation. Changing the atmospheric gas concentrations in this way may directly enhance target pest mortality or may increase target pest respiration thereby increasing the efficacy of fumigants such as phosphine. Reducing the concentration of oxygen in the enclosure (e.g. by replacement with non-flammable gases such as carbon dioxide or nitrogen) may also be necessary where the fumigant is flammable, such as is the case with ethyl formate.

4.3.2 Fumigation under vacuum

Applying a fumigant under a partial atmospheric vacuum can significantly increase the rate of fumigant penetration into a commodity, resulting in increased efficacy or the ability to reduce fumigant quantity or duration of treatment. Such treatments should be carried out in purpose-built vacuum chambers that can withstand the change in pressures and ensure minimal vacuum loss during the fumigation, and using a vacuum pump capable of attaining the atmospheric pressure required within the time frame required.

5. Enclosures and Equipment used for Fumigation

There are many potential types and designs for equipment and enclosures used in fumigation. These vary depending on the type of fumigant used, the nature of the commodity, and the conditions of the surrounding environment. The following enclosures and equipment may be necessary to ensure that a fumigation achieves the required efficacy.

5.1 Enclosures

The enclosure should be a space that can be enclosed in a manner that ensures that appropriate fumigation conditions are maintained throughout the duration of the fumigation. Examples of enclosures include purpose-built fumigation chambers, silos, freight containers, warehouses, ship’s holds or tarpaulin “tents”. The enclosure should be constructed from materials that maintain adequate fumigant concentrations over the fumigation period and prevent fumigant escape (e.g. materials that are not porous or absorbent to the fumigant). Openings should be sealed effectively. Surfaces such as soil, sand, base rock, wood and paving (stones or blocks) are not a suitable floor for a tent enclosure.

All enclosures should allow adequate access for the equipment that is required to verify that the fumigation has been conducted appropriately.

5.2 Fumigation equipment

All equipment used for measuring fumigation parameters should be calibrated according to the manufacturer's instructions and, where applicable, NPPO specifications.

5.2.1 Dosing equipment

Dosing equipment should enable the quantitative introduction of fumigant gas into an enclosure. Dosing equipment includes an appropriately safe and secure storage vessel for the fumigant, and lines that allow the fumigant to be delivered to the enclosure, and should include a device that can either measure the rate or volume of gas flow into the enclosure (e.g. a gas mass flow-meter) or measure the volume or weight loss from the gas containers supplying the enclosure (e.g. a scale or balance). In some cases, fumigant gas can be introduced into an enclosure as a solid (e.g. magnesium phosphide tablets) that releases a known volume of fumigant to achieve the required dose.

5.2.2 Gas vaporizer

Some fumigants are stored as a compressed liquid in a metal cylinder. Release and vaporization of a significant quantity of the liquid as required for fumigation absorbs a significant amount of energy. A vaporizer may be used to provide energy (as heat) during the vaporization of the liquid to a gas to ensure that the required amount of gas is provided to the enclosure. Depending on the fumigant, an appropriate pressure-resistant vaporizer should be used.

5.2.3 Heating equipment

When it is necessary to raise the temperature of the commodity and the air within the enclosure, exposed heating sources should not be used with flammable fumigants or fumigants that decompose at high temperatures (see Appendix 1 for fumigant chemical properties).

5.2.4 Gas circulation equipment

Even and quick distribution of fumigant gas introduced into the enclosure may be important for successful fumigation of a large quantity of commodity, especially with gases that diffuse relatively slowly. Rapid circulation of gas is required for the fumigation of perishable commodities or commodities that sustain damage on extended exposure to the fumigant. One or more electrical fans capable of providing adequate gas circulation should be used.

5.2.5 Instruments to measure moisture content

For commodities where the moisture content affects the efficacy of the treatment (e.g. wood), the moisture content should be measured. A moisture meter gives a reading of the approximate moisture content of the commodity. As moisture content usually varies within and between the commodities within the same lot, moisture meters need only measure within 5% of the actual moisture content. Available moisture meters include those that measure electrical resistance (pin meters) or use electrometric wave technology (pinless meters).

To ensure that the fumigation achieves the required efficacy, it may also be necessary to use instruments that measure the environmental humidity at the moment of fumigation.

5.2.6 Instruments to measure vacuum

When using vacuum during fumigation, a suitable vacuum gauge, of appropriate accuracy and sensitivity, should be used to measure and record the air pressure or vacuum drawn and maintained during the exposure or testing period. Suitable vacuum gauges may include a simple U-tube manometer or a Bourdon gauge, although specialized electronic measuring instruments are also available, and should measure within 10 Pa of the actual pressure.

5.2.7 Instruments to measure temperatures

Calibrated thermometers should be used to measure at suitable intervals the temperature in the enclosure space and, as appropriate, the external surfaces and inside the commodity before and during fumigation. The number of temperature sensors required depends on the size of the enclosure (see section 6.4).

5.2.8 Instruments to measure gas concentration

The equipment required to measure the fumigant concentration within the enclosure depends on the type of gas used. The equipment used should have an adequate accuracy (e.g. ±5% of the fumigant concentration to be achieved throughout the fumigation). The measuring equipment (e.g. sampling lines) exposed to the fumigant should be constructed from materials that do not absorb the fumigant. Fumigant sampling lines should be placed as far as possible from fumigant supply lines or dispensers, and in the area or areas of the enclosure likely to have the lowest concentration of fumigant.

6. Fumigation Procedures

Many factors may affect fumigation efficacy. These include fumigant concentration, exposure time, commodity characteristics that relate to penetration of the fumigant, commodity temperature and atmospheric temperature. Gas tightness of the enclosure, load configuration and load ratio (ratio of occupied space to the entire space) directly influence gas distribution and gas concentration during fumigation. The fumigant supply and circulation equipment (where required) should be arranged within the enclosure in a way that ensures that the fumigant concentrations required by the treatment schedule are achieved and maintained within the enclosure during fumigation.

6.1 Commodity loading

Before fumigation, the commodity should be loaded into the enclosure in a manner that ensures sufficient space for adequate circulation of the fumigant. In some cases, to ensure fumigant penetration into the commodity, separators should be used. For bulk loading, adequate circulation should be ensured, for instance by means of a recirculation system.

6.2 Packaging

When used, packaging should be of a composition and construction that does not preclude fumigant gas penetration to the commodity and prevent fumigant concentrations achieving required levels. If this is not the case, fumigant-impenetrable packing material or coatings should be removed or punctured to ensure adequate access for the fumigant. Perforated packaging should not be overlapped, as holes may become blocked.

6.3 Sorption

Sorption is the process of chemically or physically binding free fumigant on or within the fumigated commodity, packaging or enclosure. Oil, fats or porous or finely ground materials may be highly sorptive materials. Sorption may make the fumigant unavailable to kill the plant pest. The sorption rate is high at the start of the fumigation, then gradually reduces as fumigation progresses. Sorption increases the time required for aeration after fumigation. Highly sorptive commodities or packaging should not be fumigated unless concentration readings can be taken to ensure that the required minimum concentration is achieved.

6.4 Determination of fumigation temperature

Temperature is a factor in achieving the required efficacy of fumigation, in particular because it affects the respiration rate of the target pest. In general, the lower the temperature, the lower the respiration rate of the pest and the greater the dose of the fumigant or the duration of exposure needed to achieve the required efficacy.

The temperatures of the commodity and the atmosphere within the enclosure should be measured and recorded. The lowest temperature recorded in the enclosure or the commodity should be taken as the temperature at which the fumigation is undertaken. Fumigation should not proceed if, before or during fumigation, the temperature within the enclosure or the commodity falls to within 3–5 °C of the fumigant boiling point at the atmospheric pressure used. Under such conditions, heating equipment should be used to ensure adequate fumigant activity. Appendix 1 provides boiling point temperatures for some common fumigants.

6.5 Gas tightness test

The required gas tightness of an enclosure should be based on the fumigant being used. Before fumigation (preferably immediately before), a gas tightness test should be performed. However, if the enclosure is of sufficiently resistant construction and in regular use, the testing may only be necessary at intervals of, for example, 6 or 12 months, or after a number of treatments as specified by the NPPO.

Where the gas tightness of an enclosure may not be sufficient to ensure that adequate gas concentrations are maintained throughout the fumigation period, the gas tightness should be determined by measuring the half pressure decreasing time.

6.6 Introduction of the fumigant

The minimum ambient temperature that the enclosure or commodity (whichever is less) is expected to experience over the duration of the treatment should be used when determining the dosage.

The total amount of fumigant to be applied is a product of the required dosage (dose rate) and the volume of the enclosure. Correct measurement of the enclosure volume is therefore important. Excess sorption or leakage from the fumigation enclosure should be taken into consideration.

Sufficient fumigant should be applied to ensure that the required minimum concentration, as stated in the treatment schedule, is achieved. The amount of fumigant may be calculated with an appropriate formula: for examples, see Appendix 2.

The volume of the enclosure is the internal volume and should be calculated separately for each differently shaped enclosure (see Appendix 3 for examples of shapes and formulae for calculations). The volume of containers (e.g. drums or boxes) within the enclosure that are airtight and non-absorbent to the fumigant can be subtracted from the enclosure volume.

Under cool conditions, if it is required that the fumigant is introduced into the enclosure in a gaseous state, the liquid fumigant may be applied through a vaporizer. However, some fumigants such as phosphine are introduced as solids that then react with moisture and oxygen to turn into a gaseous state.

6.7 Measuring and recording

When fumigant concentration is measured and recorded, the measurements should be used to verify whether the concentration of fumigant in the enclosure is correct and that there has been no excessive leakage or sorption of the fumigant. The fumigation time begins once all the gas has been introduced and has distributed throughout the enclosure. Concentration readings should be taken according to the treatment schedule to ensure that the fumigant is evenly distributed in the enclosure over the duration of the treatment. Fumigant concentration should be continuously measured and recorded in sufficient frequency to provide confidence that the required dose has been achieved and maintained and to allow adequate calculations of the concentration–time product (CT) to be made (if required).

6.7.1 Measuring and recording the fumigant concentration

Sampling lines should be positioned in the places that are expected to be the most difficult for the fumigant to reach. The number of sampling lines required to adequately measure the fumigant concentration throughout the enclosure depends on the volume and nature of the enclosure. Purpose-built fumigation chambers may require fewer sampling lines than tent enclosures.

Depending on the commodity and the treatment schedule, it may be necessary to place further sampling lines within the commodities within the enclosure. For example, a minimum of three sampling lines may be used for the first 300 m^3 of commodity, with additional lines for commodities that are tightly packed or difficult to penetrate.

6.7.2 CT calculation

The CT can be calculated in different ways (Appendix 4). The CT values obtained from a contiguous series of readings can be added together to calculate the cumulative CT for the whole exposure period for that location. The number of contiguous measurements required to obtain a suitable estimate of the CT depends on the shape of the dose curve over the duration of the treatment.

If the sampling lines provide different readings of the fumigant concentration, the cumulative CT should be calculated using the lowest readings.

6.8 Completion of the fumigation

Once the treatment time has been completed and the required CT, temperature and minimum concentration have been achieved, the fumigation should be considered as completed. In circumstances where a minimum CT product is not initially achieved, a small extension to the fumigation period may be permitted for some fumigant types and fumigation conditions.

Indications of fumigation success can be obtained by inspection or testing to verify target pest mortality. For many fumigations, an extended post-fumigation period may be required before full pest mortality is achieved.

7. Adequate Systems for Treatment Facilities

Confidence in the adequacy of fumigation as a phytosanitary measure is primarily based on assurance that the treatment is effective against the target pest under specific conditions and that the treatment has been properly applied. Systems for treatment delivery should be designed, used and monitored to ensure that treatments are properly conducted and commodities are protected from infestation and contamination after treatment.

The NPPO of the country in which the treatments are conducted or initiated is responsible for ensuring that the system requirements are met.

7.1 Authorization of entities

In this standard, “entities” include both treatment providers and treatment facilities. Fumigation is applied by treatment providers in treatment facilities.

Treatment entities should be authorized by the NPPO in the country in which the phytosanitary treatments are conducted or initiated (the latter when fumigation takes place during transport). This authorization normally includes approval of both treatment facilities and treatment providers. The NPPO should set requirements for entity authorization, including training of personnel, fumigation procedures and adequate equipment. Specific procedures appropriate for each entity and commodity treatment should also be approved by the NPPO.

NPPOs should maintain a list of authorized entities capable of undertaking fumigation, including, where appropriate, approved facilities and approved providers.

7.2 Monitoring and auditing

The NPPO of the country in which the fumigation is conducted or initiated is responsible for the monitoring and auditing of treatment entities. Continuous supervision of fumigations should not be necessary, provided treatment programmes are properly designed and can be verified to ensure a high degree of system integrity for the entity, process and commodity in question. The monitoring and auditing should be sufficient to detect and correct deficiencies promptly.

Treatment entities should meet monitoring and auditing requirements set by the NPPO. These requirements may include:

- access for the NPPO for audit, including unannounced visits
- a system to maintain and archive treatment records and provide NPPOs with access to these
- corrective action to be taken in the event of non-compliance.

7.3 Prevention of infestation after fumigation

The consignment owner is responsible for prevention of infestation and contamination after fumigation and may cooperate with the treatment provider on how to achieve this. Measures should be implemented to prevent possible infestation or contamination of the commodity after fumigation. The following measures may be required:

- keeping the commodity in a pest free enclosure
- packing the commodity immediately in pest-proof packing
- segregating and identifying treated commodities
- dispatching the commodity immediately.

7.4 Labelling

Commodities may be labelled with fumigation lot numbers or other features of identification (e.g. locations of packaging and the treatment facility, dates of packing and fumigation) allowing trace-back for non-compliant consignments. When used, labels should be easily identifiable and placed on visible locations.

8. Documentation

The NPPO of the country in which the fumigation is conducted or initiated is responsible for ensuring that treatment providers keep appropriate records, such as raw data on fumigant concentration and temperature recorded during treatment. Accurate record keeping is essential to allow for trace-back capability.

8.1 Documentation of procedures

Procedures should be documented to ensure that commodities are fumigated in accordance with the treatment schedule. Process controls and operational parameters should be established to provide the operational details necessary for a specific authorization of a treatment entity. Calibration and quality control procedures should be documented by the treatment provider. Where appropriate, a written document on procedures should include the following:

- commodity handling procedures before, during and after fumigation
- orientation and configuration of the commodity during fumigation
- critical process parameters and the means for measuring them
- temperature and gas sensor calibration and recording, and calibration and recording for humidity sensors or moisture meters
- contingency plans and corrective actions to be taken in the event of fumigation failure or problems with critical treatment processes
- procedures for handling rejected lots
- training of personnel
- labelling (if required), record keeping, and documentation requirements.

8.2 Record keeping

The treatment provider should keep appropriate records for each treatment application. These records should be made available to the NPPO of the country in which the fumigation is conducted or initiated for auditing and verification purposes or trace-back.

Appropriate records for fumigation as a phytosanitary measure should be retained by the treatment provider for at least one year to enable the trace-back of treated lots. Information on individual fumigation records may include data on:

- name of fumigant
- identification of enclosure and treatment provider
- enclosure leakage testing records
- equipment calibration records
- commodity fumigated
- target pest
- packer, grower and place of production of the commodity
- fumigation lot number
- lot size and volume, including number of articles or packages
- identifying markings or characteristics
- date of fumigation and name of individual performing the fumigation
- any observed deviation from the treatment schedule
- the lowest air and commodity temperature
- fumigant dose and concentration records
- fumigant volumes (dose rate) calculated and added throughout fumigation.

8.3 Documentation by the NPPO

All NPPO procedures should be appropriately documented and records, including those of monitoring inspections made and phytosanitary certificates issued, should be maintained for at least one year. In cases of non-compliance or new or unexpected phytosanitary situations, documentation should be made available upon request as described in ISPM 13 (*Guidelines for the notification of non-compliance and emergency action*).

9. Inspection

Inspection should be carried out by the NPPO of the exporting country, and may be carried out by the NPPO of the importing country, to determine compliance with phytosanitary import requirements. Where live non-target pests are found after fumigation, the NPPO should consider if their survival indicates a fumigation failure and whether additional phytosanitary measures may be necessary.

10. Responsibilities

The NPPO of the country in which the fumigation is conducted or initiated is responsible for the evaluation, approval and auditing of the application of fumigation as a phytosanitary measure, including fumigation performed by the NPPO itself and by other authorized treatment entities. However, when fumigation is conducted or completed during transport, the NPPO of the exporting country is usually responsible for authorizing the entity applying the fumigation during transport and the NPPO of the importing country is responsible for verifying if the fumigation requirements have been met.

To the extent necessary, it is the NPPO’s responsibility to cooperate with other national and international regulatory agencies concerned with the development, approval and safety of the fumigation, including the training and certification of personnel conducting the fumigation, the authorization of treatment providers, and the approval of treatment facilities. Their respective responsibilities should be identified to avoid requirements that are overlapping, conflicting, inconsistent or not technically justified.

This appendix is for reference purposes only and is not a prescriptive part of the standard.

APPENDIX 1: Chemical properties of some common fumigants (at 25 ℃)

Fumigant active substance	Formula	Molecular weight (g/mol)	Boiling point (°C) (@ 1atm)	Specific gravity (gas) (air = 1.0)	Flammability limits in air (v/v %)	Solubility in water	Conversion factor (mg/litre to ppm, v/v @ 1 atm)
Carbonyl sulphide	COS	60	−50.2	2.07	12–29	0.125 g/100 ml	408
Ethane dinitrile	C_2N_2	52	−21.2	1.82	6-32	Highly soluble	470
Ethyl formate	$CH_3.CH_2.COOH$	74.08	54.5	2.55	2.7–13.5	11.8 g/100 ml	330
Hydrogen cyanide	HCN	27	26	0.9	5.6-40	Miscible	906
Methyl bromide	CH_3Br	95	3.6	3.3	10–15	3.4 v/v %	257
Methyl iodide	CH_3I	141.94	42.6	4.89	non	1.4 g/100 ml	172
Methyl isothiocyanate	C_2H_3NS	73.12	119	2.53	non	0.82 g/100 ml	334
Phosphine	PH_3	34	−87.7	1.2	>1.7	0.26 v/v %	719
Sulphur dioxide	SO_2	64.066	−10	2.26	non	9.4 g/100 ml	382
Sulphuryl fluoride	SO_2F_2	102	−55.2	3.72	non	Slight	240

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APPENDIX 2: Examples of formulae to calculate the amount of fumigant required

Sufficient fumigant should be applied to ensure that the required minimum concentration, as stated in the treatment schedule, is achieved. The amount of fumigant may be calculated with an appropriate formula.

Examples of formulae to calculate fumigants by weight and by volume are provided below.

By weight:

$$\text{Amount of fumigant (g)} = \frac{Volume\ of\ enclosure\ (m^3) \times Target\ dosage\ (g/m^3) \times 100}{\%\ Fumigant\ purity}$$

The fumigant purity is the percentage of active ingredient in the product as indicated on the label.

By volume:

$$\text{Amount of fumigant (ml)} = \left(273\ (K) + Temperature\ (℃)\right) \times$$

$$\left(\frac{\text{Gas Constant (R) } (62.363\ L.mmHg.K^{-1}.mol^{-1}) \times Volume\ of\ Enclosure\ (\text{L}) \times Target\ Dosage\ (mg/\text{L}) \times 100}{Atmospheric\ Pressure\ (mmHg) \times Molecular\ Weight\ of\ Fumigant\ (g/mol) \times \%\ Fumigant\ Purity}\right)$$

The fumigant purity is the percentage of active ingredient of the product as indicated on the label.

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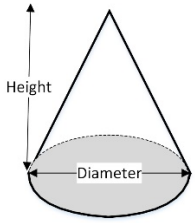
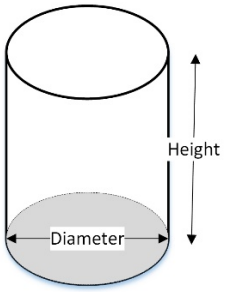
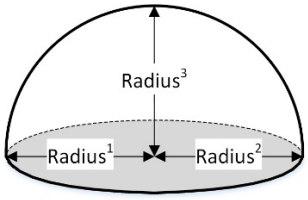
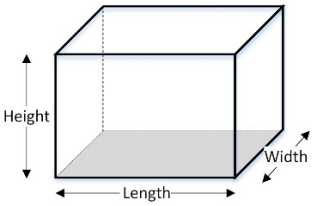
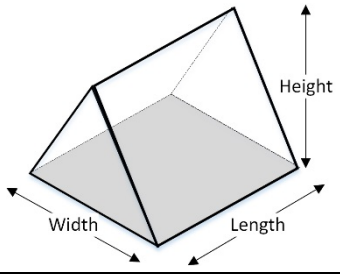
APPENDIX 3: Formulae for calculating volume of geometrical shapes

Type of geometrical shape	Geometrical structure	Formula for calculating volume
Cone		$Volume = \frac{\pi \times Radius^2 \times Height}{3}$
Cylinder		$Volume = \pi \times Radius^2 \times Height$
Dome†		$Volume = \frac{2 \times \pi \times Radius^1 \times Radius^2 \times Radius^3}{3}$
Rectangular prism		$Volume = Length \times Width \times Height$
Triangular prism		$Volume = \frac{Length \times Width \times Height}{2}$

† The formula used provides an approximate volume only.

This appendix is for reference purposes only and is not a prescriptive part of the standard.

APPENDIX 4: Examples of formulae to calculate concentration–time product (CT)

Examples of formulae to calculate the concentration–time product are provided below.

Example 1: $CT_{n,n+1} = (T_{n+1} - T_n) \times \sqrt{C_n \times C_{n+1}}$

Example 2: $CT_{n,n+1} = (T_{n+1} - T_n) \times (C_n + C_n + 1)/2$

where:

- T_n is the time the first reading was taken, in hours
- T_{n+1} is the time the second reading was taken, in hours
- C_n is the concentration reading at T_n, in g/m^3
- C_{n+1} is the concentration reading at T_{n+1}, in g/m^3
- $CT_{n,n+1}$ is the calculated CT between T_n and T_{n+1}, in $g \cdot h/m^3$

Potential implementation issues

This section is not part of the standard. The Standards Committee in May 2016 requested the Secretariat to gather information on any potential implementation issues related to this draft. Please provide details and proposals on how to address these potential implementation issues.