WHAT IS FUMIGATION?

**Fumigation** is a treatment with a chemical agent that reaches the commodity wholly or primarily in a gaseous state (ISPM No. 5 Glossary of phytosanitary terms, FAO, 1990; revised FAO, 1995)

**Fumigant** is a chemical which, at a required temperature and pressure, can exist in the gaseous state in sufficient concentration to be lethal to a given pest organism. (FAO Manual of fumigation for insect control, 2007)

**Fumigation** - is the process of application, exposure and dissipation of a toxic chemical in its gaseous state with the purpose of control of target pests in the product and its enclosure (GAFTA 2012, Fumigation Rules 132)
WHY FUMIGATE?

**IPPC - the International Plant Protection Convention**
- International cooperation in controlling pests of plants and plant products and in preventing their international spread, and especially their introduction into endangered areas.

**WTO - Sanitary and Phytosanitary Agreement (SPS)**
- Countries require the compliance of imported agricultural products with their national sanitary and phytosanitary regulations.
- The primary aim of these regulations is to protect human, animal or plant life or health from pests and diseases that may be brought in by imported agricultural products.

BEST FUMIGATION PRACTICE

**The Best fumigation practice principles:**
- the **people** involved into fumigation and around the fumigation treatment area remain safe;
- the **environment** is not harmed;
- all life stages of all target pests are exterminated;
- the **commodity** or product being treated is not damaged in any way.
Marine (in-transit) fumigation

• Marine fumigation is intended to be the cost effective solution for grain cargoes treatment preventing from idle time of ships at loading port.

• Phosphine is the only fumigant allowed for marine fumigation by IMDG Code of IMO.

• Marine fumigation is not complete until clearance at discharge port certified.

FUMIGATION PROCEDURE PRINCIPLE

Either in-port (stationary) or marine (in-transit) fumigation procedure consists of the three main stages, elapsing in different geographical locations on the ship’s track:

• Fumigant application (load port),
• Exposure period (in transit) and
• Cargo degassing (discharge port).

An error at any stage results in general fumigation failure.
## IN-TRANSIT FUMIGATION DIAGRAM

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fumigation</strong></td>
<td>Inspection, R/C install.</td>
<td>Briefing of crew, medical &amp; safety kit</td>
<td>Application, testing, Certification</td>
<td>Gas generation, equation</td>
<td>Exposure period (CTP)</td>
<td>Initial venting of cargo</td>
<td>Degassing, disposal, Clearance</td>
<td>Safety Monitoring</td>
<td>R/C pipe removal</td>
</tr>
<tr>
<td></td>
<td>1 - 3 + hours</td>
<td>1 – 3 + hours</td>
<td>6 + hours</td>
<td>2 - 10 + days</td>
<td>4 - 15 + days</td>
<td>12 + hours</td>
<td>1 hour - 3 days</td>
<td>1 - 10 + days</td>
<td>1 - 6 + hours</td>
</tr>
<tr>
<td><strong>Carriage</strong></td>
<td>Port Formalities</td>
<td>Loading Operations</td>
<td>Port Formalities</td>
<td>Voyage (Transit) Time at Sea</td>
<td>Port Formalities</td>
<td>Discharging Operations</td>
<td>Port Formalities</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 - 3 + hours</td>
<td>1 – 10 + days</td>
<td>1 - 3 + hours</td>
<td>1 - 60 + days</td>
<td>1 – 3 + hours</td>
<td>1 - 10 + days</td>
<td>1 – 3+ hours</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## FACTORS AFFECTING FUMIGATION EFFICACY

<table>
<thead>
<tr>
<th>FACTORS</th>
<th>CONTROLABILITY</th>
<th>EFFECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target organism</td>
<td>Non - controllable</td>
<td>Tolerant stages, mites</td>
</tr>
<tr>
<td>Temperature</td>
<td>Non - controllable</td>
<td>Not effective &lt;+10°C</td>
</tr>
<tr>
<td>Moisture content</td>
<td>Non - controllable</td>
<td>Not effective &lt; 40%</td>
</tr>
<tr>
<td>Fumigant quality</td>
<td>Controllable</td>
<td>“Cheaper” does not mean &quot;better’’</td>
</tr>
<tr>
<td>Gas tightness</td>
<td>Controllable</td>
<td>CTP (Concentration Time Product)</td>
</tr>
<tr>
<td>Gas penetration</td>
<td>Controllable</td>
<td>Poor &gt;12 m depth</td>
</tr>
</tbody>
</table>
Tablet reaction

Phosphine gas

Hydrogen Phosphide (or phosphine) – PH₃ is released from metal phosphide fumigants in the presence of atmospheric moisture and moisture of the goods to be treated.

Chemical reactions of metal phosphides:

- Aluminium Phosphide:
  $$\text{AlP} + 3\text{H}_2\text{O} \rightarrow \text{Al(OH)}_3 + \text{PH}_3$$

- Magnesium Phosphide:
  $$\text{Mg}_3\text{P}_2 + 6\text{H}_2\text{O} \rightarrow 3\text{Mg(OH)}_2 + 2\text{PH}_3$$

TABLET FUMIGANT FORMULATION

AlP₁ tablet (3g) => PH₃ gas (1g) = abt. 700 ppm

<table>
<thead>
<tr>
<th>PH₃ in air</th>
<th>%</th>
<th>ppm</th>
<th>g/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>At 15°C, 760 mmHg</td>
<td>1.0</td>
<td>10 000</td>
<td>14.39</td>
</tr>
<tr>
<td>1 AlP tablet release</td>
<td>0.07</td>
<td>694.9</td>
<td>1</td>
</tr>
<tr>
<td>Lower Flammability Limit</td>
<td>1.6</td>
<td>16 000</td>
<td>23.0</td>
</tr>
<tr>
<td>Threshold Limit Value (TLV)</td>
<td>0.3 (0.1)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
HIGH MOISTURE CONTENT RESULT

Rapid phosphine gas liberation due to wet cargo conditions resulting in explosion

GAS TIGHTNESS

GAS TIGHTNESS is the key factor for fumigation success:

- **Safety**: Preventing the crew from being exposed to dangerous gas concentrations
- **Efficacy**: Maintaining the lethal concentration of fumigant during the time necessary to control the target pests
- **Economy**: Preventing expensive products and materials waste
GAS TIGHTNESS

- The Australian Standard (AS2628) provides an industry benchmark for pressure testing sealable, gas-tight silos.
- Any silo sold as a ‘sealed silo’ still needs to be pressure tested to ensure it is gas tight.
- Carry out a five-minute half-life pressure test, each year before harvest and before every grain fumigation.
- Regular maintenance is the key to ensuring a sealable silo remains gas tight.

TYPICAL GAS LEAKAGE SOURCES

Should be effectively sealed before fumigant application.
PHOSPHINE PENETRATION

Passive fumigation

- **Phosphine** gas moves down through the grain mass very slowly by own gravity
- After 5 – 7 days some phosphine gas should reach 10 - 12 m at effective concentrations
- **Phosphine** gas very unlikely to reach 15 - 20 m at effective concentrations however long the voyage
- **Not recommended** for shipments over 10 000 mt

- Should be effectively sealed before fumigant application
**PHOSPHINE PENETRATION**

**Active fumigation**

- Phosphine gas is drawn from cargo surface to bottom of hold by electric blower through plastic piping.
- Phosphine gas permeates through cargo mass as re-circulation continues during voyage.
- Is recommended for shipments over 10,000 mt or when grain or commodity is greater than 12 m in depth.

**RE-CIRCULATION SYSTEM**

Installation of plastic pipes for the re-circulation system before loading operations.
EXPOSURE TIME (UK)

Concentration time product (CTP)

Data from trials done by Pest Infestation Control Laboratory, Ministry of Agriculture Fisheries & Food, [MAFF], UK

A. \( \text{CTP} (t \ 25^\circ \text{C}) = 158 \text{ g h/m}^3 \)
   - \( \text{PH}_3 \) gas release (good quality) \( 1 \text{ day} \)
   - Penetration towards the bottom (12 m) \( 10 \text{ days} \)
   - Action on the target organism \( 4.5 \text{ days} \)
   \( (T = 158 / 1.5 \text{ g/m}^3 (\text{PH}_3) = 105 \text{ h} = 4.5 \text{ days}) \)
   \( \text{TOTAL:} \ 15.5 \text{ days} \)

B. \( \text{CTP} (t \ 15^\circ \text{C}) = 288 \text{ g h/m}^3 \)
   - \( \text{PH}_3 \) gas release (good quality) \( 1 \text{ day} \)
   - Penetration towards the bottom (12 m) \( 10 \text{ days} \)
   - Action on the target organism \( 8 \text{ days} \)
   \( (T = 288 / 1.5 \text{ g/m}^3 (\text{PH}_3) = 192 \text{ h} = 8 \text{ days}) \)
   \( \text{TOTAL:} \ 19 \text{ days} \)

Grain weevil (Sitophilus granarius L.)
### EXPOSURE TIME (USDA)

| Application Method and Minimum Dosage Rate Per 1,000 Cubic Feet of Storage Space | CARGO HOLD DEPTH IN METERS* | FUMIGANT EXPOSURE TIME IN DAYS |
|---|---|---|---|---|---|
| | < 6 | 6 – 12 | >12 – 20 | >20 |
| Surface Application | | | | |
| 45 grams of metal phosphide per 1,000 cu. ft | | | | |
| Subsurface / Trench-in Application | | | | |
| 45 grams of metal phosphide per 1,000 cu. ft | | | | |
| Recirculation Application – Method A | | | | |
| 33 grams of metal phosphide per 1,000 cu. ft | | | | |
| Recirculation Application – Method B | | | | |
| 45 grams of aluminum phosphide pellets per 1,000 cu. ft | | | | |
| 30 grams of magnesium phosphide per 1,000 cu. ft | | | | |

* Cargo Hold Depth is the length from the bottom of the hold to the top of the coaming.

### DOSAGES FOR INLAND FUMICATION

* Recommended dosages of phosphine for various types of fumigation (Source: Detia Gegesch) *

<table>
<thead>
<tr>
<th>Type of fumigation</th>
<th>Dosage range (g of PH3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silo (filled)</td>
<td>11.3 grams per 1 ton</td>
</tr>
<tr>
<td>Silo (empty)</td>
<td>5 grams per m³</td>
</tr>
<tr>
<td>Cereals in flat storage and bag stacks</td>
<td>14 grams per 1 ton</td>
</tr>
<tr>
<td>Spices and tea in bag stacks</td>
<td>2 grams per m³</td>
</tr>
<tr>
<td>Other products in bag stacks</td>
<td>10 grams per 1 ton</td>
</tr>
<tr>
<td>Containers (depending on the commodity)</td>
<td>9 grams per 1 ton or 6 grams per m³</td>
</tr>
<tr>
<td>Tobacco</td>
<td>1 grams per m³</td>
</tr>
</tbody>
</table>
## TEMPERATURE VS EXPOSURE

![Temperature Scale](image)

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Pellets</th>
<th>Tablets</th>
<th>Bags</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 5ºC</td>
<td><strong>DO NOT FUMIGATE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0 – 12ºC</td>
<td>8 days</td>
<td>10 days</td>
<td>14 days</td>
</tr>
<tr>
<td>12 – 15ºC</td>
<td>4 days</td>
<td>5 days</td>
<td>9 days</td>
</tr>
<tr>
<td>15 – 20ºC</td>
<td>3 days</td>
<td>4 days</td>
<td>6 days</td>
</tr>
<tr>
<td>20 – 25ºC</td>
<td>2 days</td>
<td>3 days</td>
<td>4 days</td>
</tr>
<tr>
<td>Above 25ºC</td>
<td>2 days</td>
<td>3 days</td>
<td>3 days</td>
</tr>
</tbody>
</table>

## MOISTURE VS EXPOSURE

**At 10ºC**
- PH₃ is produced 2.3 times faster in 15% moisture wheat than in 10% moisture wheat;
- PH₃ is produced 1.5 times faster in 18% moisture corn than in 13% moisture corn.

**At 30ºC**
- PH₃ is produced 1.9 times faster in 15% moisture wheat than in 10% moisture wheat;
- PH₃ is produced 1.3 times faster in 18% moisture corn than in 13% moisture corn.
FUMIGATION SAFETY

3.3.2.7 The ship should carry:

1. gas-detection equipment and adequate fresh supplies of service items for the fumigant(s) concerned, together with instructions for its use and the occupational exposure limit values set by the flag State regulations for safe working conditions;
2. instructions on disposal of residual fumigant material;
3. at least four sets of adequate respiratory protective equipment; and
4. a copy of the latest version of the Medical First Aid Guide for Use in Accidents Involving Dangerous Goods (MFAG), including appropriate medicines and medical equipment.
FUMIGATION CERTIFICATION

A. IN-PORT FUMIGATION
1. Fumigant application
2. Exposure period
3. Cargo degassing
4. Efficacy control
5. Fumigation certificate

B. IN-TRANSIT FUMIGATION
1. Fumigant application
2. Fumigation certificate
3. Exposure period
4. Cargo ventilation
5. Surprise! (???)

LACK OF FUMIGATION CLEARANCE MAY RESULT IN:

- Poisoning;
- Fire;
- Pollution;
- Damage;
- Demurrage
# Fumigation Certificates Comparison

<table>
<thead>
<tr>
<th>Fumigation Certificate (In-port Fumigation)</th>
<th>Fumigation Certificate (In-transit Fumigation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Issued on completion of treatment;</td>
<td>• Issued at the beginning of treatment;</td>
</tr>
<tr>
<td>• Both safety and efficiency are certified before sailing;</td>
<td>• Neither safety nor efficiency can be certified before sailing;</td>
</tr>
<tr>
<td>• No extra services at discharge required</td>
<td>• Clearance at discharge required</td>
</tr>
</tbody>
</table>

## Fumigation Clearance

**Clearance on Arrival**

|---|--------------------|----------------------|---------------------|--------------------------|

**IMO Recommendations:**

5.1.1. Qualified operators only

5.1.2. Clearance certificate

**IMFO Solution:**

Port-to-Port Service
Key factors for fumigation success:

- **Instrumental** gas tightness test of cargo holds;
- The minimum effective fumigant **dosage**;
- The minimum effective fumigant **exposure** period;
- The maximum commodity **depth** for passive fumigation (w/o R/C);
- Fumigation **clearance** certification on arrival.

### DO

- Remember that fumigant application is the **first stage** of fumigation only;
- Always consider specific requirements of **destination** country when choosing fumigation method;
- Make sure of the ship’s IMO/IMDG Code compliance (safety and medical **kits** availability on board);
- Always use **qualified** fumigation providers at load and discharge ports.

### DO NOT

- Delay contracting fumigator until loading operations start;
- Rely on marine fumigation success based on fumigant application only;
- Sacrifice fumigant exposure time for sake of voyage time;
- Engage ship’s personnel into operations with fumigants (against IMO/IMDG).
Thank you for attention!

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A.Zrely@greencoltd.com.ua