Unit 3: Characteristics and Effects of Fumigants

Learning Objectives

After reading this unit, the reader will be able to:

- Describe several characteristics of fumigants.
- Explain how these characteristics can affect how, when, and where you use a particular fumigant.
- Identify several factors that can affect fumigant performance during stored product and soil fumigation.

Like all pesticides, several factors can affect how well a fumigant will work. These range from characteristics of the fumigant itself (boiling point, molecular weight, etc.) to external factors such as air movement, temperature, and applicator knowledge and skill. This unit will describe each of these factors. You will discover how small differences can have a big effect on fumigant performance and safety.

Terms to Know

Absorption – When fumigant molecules penetrate into a material (commodity, soil, or other item being fumigated).

Adsorption – When fumigant molecules stick to the surface of a material (commodity, soil, or other item being fumigated).

Aeration – *Fumigant application:* The process of replacing fumigant-containing air or water with fresh air and/or water that contains little or no fumigant. Aeration must follow all fumigation operations.

Boiling Point – The temperature at which a liquid becomes a gas.

Desorption – The liberation or removal of a fumigant from treated surfaces and/or substances.

Diffuse – To spread or distribute, to move in all directions.

Dosage – The concentration of a fumigant (ounces, pm, etc.) times the exposure time (hours, minutes, etc.). The dosage requirements depend on the pest, the fumigant, the temperature, the rate of leakage (some leakage is inevitable), and many other factors.

Equilibrium – Even distribution. For example, a fumigant has reached equilibrium when there is an equal concentration of gas throughout a given structure.

Field Capacity – The moisture level of soil at which air has largely replaced water in soil macropores but not micropores. For example, at 50 percent field capacity, the total space between soil particles is shared equally by air and water, with most of the water being found in soil micropores.

Inert – Not reactive.

Macropores – The large spaces between soil particles in which air and water can move readily.

Metabolism – All chemical reactions that take place in a living thing. For example, insects metabolize food to produce energy.

Micropores – The small spaces between soil particles where little air movement occurs and water moves slowly. Plants absorb most of the water they need from soil micropores.

Molecular Weight – The sum of the atomic weights of all the atoms in a molecule. All fumigants have a unique molecular weight.

Molecule – The smallest particle of a substance that retains all of the properties of the substance.

Pesticide Resistance – The ability of an organism to tolerate a pesticide. There are different levels of resistance. For example, some insects may be sensitive, weakly resistant, or strongly resistant to a specific insecticide. Total resistance is immunity.

Seal – To enclose an area so that fumigant gas cannot escape too quickly. A good seal will contain a lethal amount of gas long enough to kill the target pests.

Soil Texture – The relative proportion of the different sizes of mineral particles – sand, silt, and clay – that make up a soil.

Solubility – How readily a substance will dissolve in a liquid.

Sorption – Adsorption and/or absorption.

Stratification – When fumigants rise or fall, making layers of gas within a confined area. Diffusion is incomplete, leaving some areas untouched by the fumigant. Stratification results in an incomplete treatment.

Tilth – The physical condition of soil that determines the ease at which it can be tilled or cultivated and its suitability for seed germination and plant growth.

Vapor Pressure – The pressure exerted by a liquid or a solid as it volatilizes (becomes a gas).

Vaporize – When a solid or liquid turns into a vapor (gas).

Volatility – How readily a substance transforms from a solid or liquid into a gas.

Unit 1 defined a fumigant as a pesticide in gas form. At a high enough concentration, this gas can kill bacteria, fungi, insects, nematodes, and weeds. Unit 1 also explained that as a gas, fumigant molecules can move into tiny gaps such as between kernels of grain or through small openings in the soil. This is why fumigants are so effective in certain situations.

This unit will focus on factors that affect fumigant performance: both characteristics of the fumigant and external factors.

Characteristics of Fumigants

There are many fumigants on the market. Your job is to select the best product for the pest and situation at hand.

Boiling point, molecular weight, specific gravity, solubility, and flammability are different for all fumigants. Each characteristic makes a fumigant act a certain way under certain conditions. Understanding how these factors affect application will help you select the best product for the job.

Always consult the label information for each product that you consider. It will contain information on the following characteristics.

Molecular Weight and Specific Gravity

All substances, including air and fumigants, have a "molecular weight." The molecular weight of air is about 29. Fumigants with a molecular weight lower than 29 are lighter than air and may rise. Those with a molecular weight higher than 29 are heavier than air and may sink.

All substances also have a "specific gravity." The specific gravity of air is 1. Fumigants with a specific gravity greater than 1 are heavier than air and may sink. Fumigants with a specific gravity less than 1 are lighter than air and may rise.

Gases are unique in that their specific gravities are related to their molecular weights. For example:

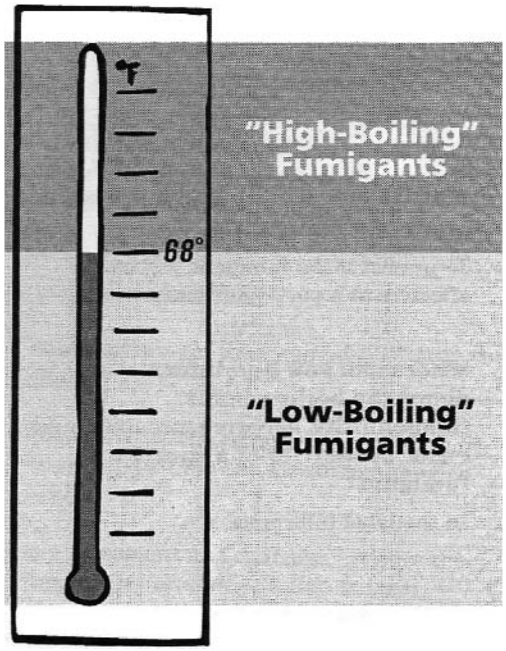
$$\text{Specific Gravity of a Fumigant} = \frac{\text{Molecular Weight of a Fumigant}}{\text{Molecular Weight of Air}}$$

NOTE: This relationship is valid only when the temperature and pressure of the fumigant and air are the same.

The molecular weight and specific gravity of a fumigant can help you determine how well it will distribute throughout an area. Even distribution is referred to as an "equilibrium." Most fumigant gases are heavier than air. For example, the molecular weight of methyl bromide is 94.95, making its specific gravity 3.28. This means methyl bromide is 3.28 times heavier than air. When the molecular weight of a fumigant is greater than or less than air, you may need to use fans and/or other tactics to achieve equilibrium during fumigation.

Boiling Point

Boiling point is the temperature at which a fumigant becomes a gas. Most fumigants reach their boiling point between -125.9°F and 233.6°F. "Low-boiling" fumigants become gases below room or moderate outdoor temperatures (68° to 77°). To stabilize these chemicals, manufacturers keep them as liquefied gases under pressure in cylinders or cans. Fumigants with boiling points higher than 68°F, "high-boiling" fumigants, are initially liquids at normal fumigation temperatures. While these chemicals have slow evaporation rates, they will eventually vaporize during treatment. To use these products, you may need to wait for a warm day or increase the temperature within the area you plan to treat.



Boiling point also indicates the vapor pressure of a fumigant. In general, the higher the boiling point, the lower the vapor pressure, and the slower a fumigant will change to a gas.

Solubility

Solubility tells you how readily a fumigant gas will dissolve in certain materials, depending on their moisture content.

Some fumigants are soluble in water, oil, or other liquids. These pesticides may dissolve in commodities that have high moisture or oil contents. For example, methyl bromide is soluble in oil. If you use this fumigant to treat commodities with a high oil content, such as peanuts or soybeans, it may dissolve in the oil. Once dissolved, the methyl bromide may be difficult to aerate. This is particularly a problem when multiple treatments of these commodities are necessary.

Flammability

Some fumigants, such as phosphine, are extremely flammable. Formulations of flammable fumigants may contain fire retardants. For example, some products that produce phosphine also produce ammonia and carbon dioxide. However, the best way to prevent fire hazards is to apply and dispose of fumigants properly. Always read the label information to learn which conditions favor fire or explosions. The label information will describe how to avoid these problems.

Table 3-1. Physical and chemical properties of fumigants commonly in use at the time this manual was printed.

Fumigant	Molecular Weight	Boiling Point (°F)	Specific Gravity*	Flammability (in air)
Methyl Bromide Phosphine	94.95 34	38.4 -125.9	3.28 1.17	nonflammable flammable
Sulfuryl Fluoride	102.07	67	3.52	nonflammable

**Specific gravity = the molecular weight of a fumigant divided by the molecular weight of air (29).*

Test Your Knowledge

Q. How can the molecular weight of a fumigant affect its ability to diffuse throughout a room?

A. Fumigants with molecular weights lower than 29 are lighter than air and may rise. Those with molecular weights higher than 29 are heavier than air and may sink. Both extremes may require you to use fans and other means to prevent stratification.

Q. Define stratification.

A. When air and fumigant form layers and do not mix.

Q. What does the solubility of a fumigant tell you?

A. Solubility tells you how readily a fumigant will dissolve in water, oil, or other substances. For example, if you apply a fumigant that is soluble in oil to grain that has a high oil content, the fumigant will dissolve into the oil of the grain. The fumigant will remain in the oil and contaminate the grain.

Q. Why do you need to know the boiling point of a fumigant?

A. To predict if the fumigant will be effective at a particular temperature.

Q. Where can you find information about the boiling point, flammability, sorptive capacity, and other properties of a specific fumigant?

A. In the label information.

Factors That Affect Fumigation of Stored Food Products

A variety of factors affect the use and success of fumigants. Some of the most important factors in stored product fumigation are:

- Pest characteristics
- Temperature of the commodity or area you plant to treat
- Moisture in the commodity or area to be fumigated and in the air surrounding/ within it
- Air movement and diffusion within the area you fumigate
- Construction of the structure within which you treat an item or the quality of the seal enclosing the area to be fumigated, and
- Applicator knowledge and skill

Pest Characteristics – Raw Product Fumigation

Several aspects of the pest's biology can influence the effectiveness and timing of a fumigant treatment. These include:

- The insect's stage of growth. Pupa and eggs are the hardest to kill because they are not active. Adults and young larvae are most susceptible.
- The activity level of the insect. Active adults and larvae are easier to kill than are inactive or hibernating adults and larvae. This is because active insects have a higher metabolism, allowing them to process the pesticide faster. Therefore, whenever possible, wait until the insects are mature and active before fumigating.
- The feeding habits of the insect. Insects that develop outside grain kernels are usually more susceptible to fumigants than species that develop inside grain kernels.
- The size of the infestation. Heavy infestations are more difficult to control. Masses of insects generate large amounts of dust, damaged grain, webbing, and cast skins. These materials interfere with fumigant penetration and increase sorption.
- Some insects have "resistance" to fumigants. Resistance is the ability of an organism to tolerate a pesticide. There are various levels of resistance. For example, some insects may be sensitive, weakly resistant, or strongly resistant to a specific insecticide. Total resistance is immunity. Frequent fumigation at dosages too low to kill all insects promotes problems with resistance.

Although this information is true for most insects, application recommendations vary with the pest. Use the information from Unit 2 to help you identify the most susceptible stage(s) of development and activity level(s) of the pest that you wish to control.

Temperature

"Temperature" refers to the temperature:

- Of the commodity that you plan to treat, or
- Under the tarp or within the structure where treatment will occur

Temperature affects both the dosage and exposure period needed for pest control. As a rule, the higher the temperature, the less fumigant you will need. This is because as temperature increases, insect metabolism increases. As metabolism increases, insects breathe faster absorbing more fumigant. Less fumigant is needed to kill the pest. As the temperature drops, the reverse is true. Insect breathing slows. You may need to add fumigant to get the same level of control. Below 40°F, fumigants may not be effective at all.

Higher temperatures also increases the volatility of fumigants. Volatility refers to how readily a substance turns into a gas (vaporizes). The higher the volatility, the faster a fumigant disperses and penetrates. Sorption by the material being treated decreases and less fumigant is needed. (See "Sorption" later in this unit to learn how temperature affects this process.)

Finally, temperature can cause a fumigant to "stratify." Stratification occurs when air and fumigant form layers and do not mix. In general, if the temperature of a fumigant is significantly lower than air, stratification becomes more severe.

For best results, fumigate when temperatures are above 60°F.

Moisture

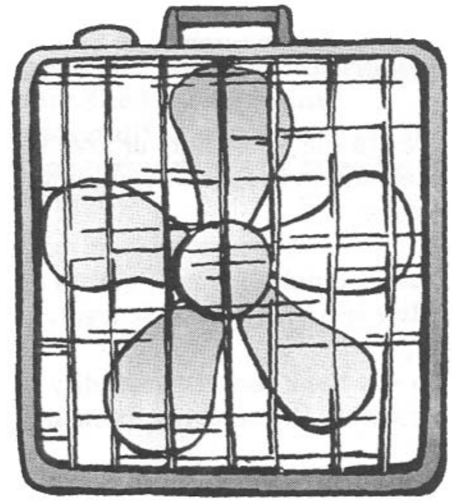
As the moisture content of a commodity increases, sorption increases. This makes it more difficult for a fumigant to penetrate a commodity. Therefore, products with high moisture contents require higher doses of fumigant. High moisture contents also increase the potential that residues will exceed legal limits due to the increased sorption and slow desorption.

On the other hand, some dry fumigant formulations (such as phosphine tablets and pellets) need humidity to generate gas. These are called "moisture-activated" fumigants. If the air is too dry or the moisture content of the commodity is too low, these fumigants will stay in solid form.

Air Movement

To be effective, a fumigant gas must diffuse (spread) evenly and quickly throughout the commodity or space that you are treating. The gas must enter small crevices, cracks, or spaces so that a lethal concentration contacts every pest. Even distribution is called an "equilibrium." The ability of a fumigant to reach equilibrium depends on several things. In general, gases diffuse more quickly at higher temperatures and lower air pressures. Fumigants also spread faster when their initial concentration is high and the penetration distance is short.

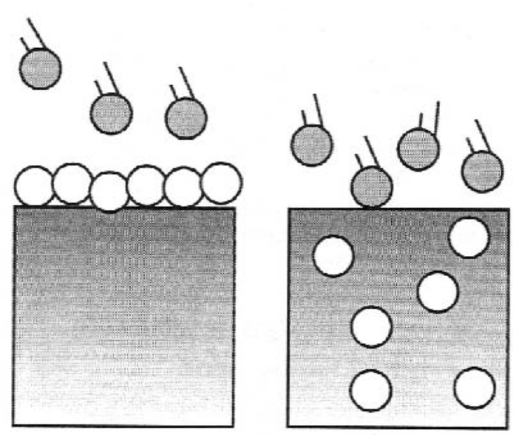
Some fumigants require air circulation to diffuse quickly. Without air circulation, the air and fumigant may form layers and fail to mix – a condition called "stratification." Fans, ducts, and blowers are often necessary. Select equipment that fits the job. Fans are usually sufficient to stir the air in open areas. Confined areas with tightly packed commodities may require blowers or ducts to move the fumigant from one place to another. However, once the fumigant reaches equilibrium, the problem of stratification decreases.



Sometimes you will need help to distribute a fumigant throughout a treatment area.

Sorption

When a fumigant gas contacts materials, gas molecules undergo the process of "sorption." There are two types of sorption: adsorption and absorption. Adsorption occurs when fumigant molecules stick to the surface of a treated material. Absorption occurs when the molecules penetrate into the material. Both types of sorption reduce the effectiveness of fumigants by removing molecules from the air. These bits of fumigant are no longer able to move freely and kill the target pest(s). Sorption also slows "aeration" – the process by which fumigant is released after treatment.



Adsorption vs. absorption

Some fumigants are more subject to sorption than others are. Read the label information for sorption information about each product you consider.

Commodities and the structures that house them also vary in their "sorptive" capacity. Loads of grain with many small pieces have a lot of surface area and are more sorptive. Inert surfaces such as metal are less sorptive.

Knowing how sorptive certain chemicals and commodities are is critical. This information will help you determine how much fumigant to use, how long to contain the fumigant, and how long to aerate the treatment area or product. When sorption levels are high, you will need to use more fumigant. You will also need to increase the treatment time because diffusion is slower. When treatment is complete, aeration periods must be long enough to allow the fumigant to slowly "desorb" from the commodity. If aeration is too short, traces of fumigant may remain sorbed to the product. This can cause toxic residues, off-flavors, or odors in the treated material.

As a rule, sorption is greater at cold temperatures. For example, if the temperature inside a warehouse is cool during fumigation, the commodity(ies) will absorb or adsorb the fumigant at a higher rate. You will need to use more fumigant. The same is true for aeration. Aeration normally takes longer when temperatures are low or when products are cold.

Adsorption is usually greater with fumigants of high molecular weights and low vapor pressures.

Construction of the Structure

Fumigant label information lists a range of dosages form which to choose. Each dosage fits a specific situation. The most important factor in selecting a dosage is the tightness of the structure. The ability of a building to hold a fumigant directly affects the amount of gas needed to sustain a lethal concentration throughout. Higher dosages are needed for structures that are of "loose" construction. For example, warehouses tend to have gaps around windows, doors, and wall joints. Lower doses may be adequate for "tightly" constructed structures such as boxcars and fumigation chambers.

For loosely built structures, it is often better to "seal" the area than to increase the amount of fumigant you use.

Seal

A tight seal around a structure or commodity ensures effective fumigation and the safety of those nearby. You can seal a structure or commodity in one of three ways:

1. Tape and seal all potential openings within a structure with plastic and fumigation tape.
2. Place a gastight tarp over the item or structure.
3. Use a fumigation chamber.

The quality of a seal is important. It can affect:

- The amount of fumigant needed (the tighter the seal, the less gas that will escape, and the less fumigant that will be needed), and
- The length of time necessary to kill the target pest (the tighter the seal, the more constant the fumigant concentration, and the less time needed to achieve control).

A fumigation chamber is an example of a tight seal. Little gas escapes from a well-constructed chamber. On the other hand, placing a gastight tarp over commodities or structures can provide a poor-to-excellent seal depending on:

- The condition of the tarp
- The tightness of the seams, and
- The type of ground seal

Structures in sandy soils or with dirt crawl spaces may lose gas through the soil. Commodities sitting on concrete floors may lose gas through the concrete. To prevent these problems, always tarp the top and bottom of structures and items on porous bases.

Some structures may be too large to tarp, such as warehouses or large grain bins. In these situations, a tape-and-seal job may be required. Always seal doors, windows, and vents. This will prevent heavy loss through large gaps. In grain bins, you should also seal unloading augers, roof exhaust vents, and eave gaps (openings where the roof meets the sidewalks). Although tape-and-seal fumigation can prevent many leaks, the fumigant can penetrate untarped walls, even when the walls are made of solid materials like brick and concrete. You will usually need more fumigant to replace what is lost through untarped walls.

Also, consider the condition of the structure and the type of construction. A wooden structure, even when sealed, will not retain fumigants as well as one of brick, concrete, or steel. This is because wood is more porous than the other materials. For example, round steel bins retain fumigant better than flat grain-storage bins, which are usually made of wood. In addition, wooden structures are often not built as "tightly" as structures made with other materials. For these reasons, it is often necessary to tarp wooden structures during fumigation.

Applicator Knowledge and Skill – Raw Product Fumigation

In the end, you, the applicator, are the most important variable in raw product fumigation. Your education and training will directly affect the success and safety of your operation. Know and understand the properties of every product you plan to use. Consider how different factors will affect treatment. Understand the site – its limitations and its strengths. Choose your dosage and application methods accordingly.

Test Your Knowledge

Q. List several factors that influence a fumigant's effectiveness.

A. 1. Diffusion: how well a fumigant penetrates a commodity or how well it is circulated throughout an area.

2. The sorptive capacity of the commodity to be fumigated.

3. The temperature of the commodity or space to be fumigated.

4. The moisture content of the commodity or area to be fumigated and the air surrounding/within it.

5. The construction of the structure to be fumigated or the structure within which you will treat an item.

6. The quality of the seal enclosing the area to be fumigated.

7. The characteristics of the target pest.

8. The level of resistance a pest may or may not have.

Q. As a rule, at what temperature is fumigation most effective?

A. Above 60°F.

Q. Define volatility. How does the volatility of a fumigant affect dosage?

A. Volatility refers to how readily a substance turns into a gas (vaporizes). The higher the volatility, the faster fumigant disperses and penetrates. Sorption by the material being treated decreases and less fumigant is needed.

Q. What aspects of the pest and pest damage can affect fumigation? How does each aspect affect fumigant performance?

A. 1. The insect's stage of growth. Pupa and eggs are the hardest to kill because they are not active. Adults and young larvae are most susceptible.

2. The activity level of the insect. Active adults and larvae are easier to kill than are inactive or hibernating adults and larvae. This is because active insects have a higher metabolism, allowing them to process the pesticide faster.

3. The feeding habits of the insect. Insects that develop outside grain kernels are usually more susceptible to fumigants than species that develop inside grain kernels.

4. The size of the infestation. Heavy infestations are more difficult to control. Masses of insects generate large amounts of dust, damaged grain, webbing, and cast skins. These materials interfere with fumigant penetration and increase sorption.

Q. What is the difference between adsorption and absorption? How do they affect the performance of a fumigant?

A. Adsorption occurs when fumigant molecules stick to the surface of the treated material. Absorption occurs when the molecules penetrate into the material. Both types of sorption reduce the effectiveness of fumigants by removing molecules from the air. These bits of fumigants are no longer able to move freely and kill the target pest(s). Sorption also slows "aeration" – the process by which the fumigant is released after treatment.