COOPERATIVE EXTENSION SERVICE
UNIVERSITY OF KENTUCKY—COLLEGE OF AGRICULTURE

Pesticide Applicator Training Manual

Anti-Microbial Pest Control

Category 15

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CHAPTER ONE

INTEGRATED MICROBIAL PEST MANAGEMENT

Microbial pests include certain viruses, bacteria, and algae that are able to grow and reproduce in the air wash and cooling systems used in industrial processes, and in paper mills. Examples of how people are affected by microorganism pests include the 1976 Philadelphia, Pennsylvania, and the 1986 Romulus, Michigan outbreaks of Legionnaires' disease. In both cases several persons died because of a disease caused by bacteria, *Legionella pneumophila,* growing in the air cooling system of the buildings they occupied.

This manual is an introduction to the techniques used in integrated microbial pest management programs. **Integrated Pest Management (IPM)** is defined as the use of all available tactics or strategies to manage pests so that an acceptable yield and quality can be achieved economically with the least disruption to the environment. Several factors highlight the need for IPM programs. Sole reliance on pesticides has proven to be detrimental to the environment. Pests can develop resistance due to the overuse of certain chemicals. Applicators often spend more money than is necessary for pest management. IPM provides the applicator with a diverse pest management program that avoids reliance on one technique. Many successful IPM programs have reduced energy and pesticide use, thereby saving money and causing less harm to our environment.

Normally, the goal of an IPM program is to reduce the occurrence of plant problems and maintain insect populations and disease problems at levels where aesthetic and economic losses are tolerable. Rarely is total eradication of a pest a realistic goal. However, in microbial pest management the eradication of pests in specific equipment is possible and necessary because of the limited area treated and the potential hazard to persons and property the pests may cause if not controlled completely.

The basic components of an IPM program include:

- Regular monitoring and early detection of disorders.
- Proper identification of microbial pest organisms.
- Determination of economic significance.
- Selection of management methods.
- Evaluation of management methods

MONITORING AND DETECTION

It is extremely important to detect pest infestations before they become a problem. Failure to do so can result in increased cost of control, ineffective management measures, potential damage to the equipment or product (i.e. paper in a pulp mill), and increased cost for cooling when treating a cooling tower.

Proper pest detection requires frequent and careful visual checks of cooling or process equipment, a knowledge of the common microbial pests, an ability to recognize potential problems, periodic bacteria cultures, and a thorough knowledge of the system that is being maintained. Realizing that cooling towers, evaporative condensers, and similar open recirculating systems by design can scrub a wide and varied group of organisms from the air during normal operation should alert the manager to their potential growth in the system. Closed recirculating cooling water systems are much less subject to operating problems caused by microorganisms, but some pests (e.g. fungal slimes) are sometimes encountered Also, once-through cooling systems involve a limited group of organisms, rarely including algae, for example.

IDENTIFICATION

The more that is known about microorganisms and the factors that influence their growth, the easier and more successful pest management becomes. When you identify a pest, you gain important biological information that influences management decisions. You can determine what type of controls are necessary and what the management program should be. Knowing a pest's life cycle may assist in selecting the pesticide treatment program and time of application.

Weather conditions and activities in the surrounding area can effect the population of organisms. For example, the growth of algae in cooling systems can be enhanced if the cooling tower is located near a bakery, candy plant, or similar area where atmospheric conditions tend to foster rapid algae growth. Other factors to consider include the amount of sunlight and oxygen that is available. Each water treatment system and its problems must be considered individually.

ECONOMIC SIGNIFICANCE

Remember that when dealing with microbial organisms that a relatively small number of pests have a great potential for disease, product damage, or equipment shutdown (unlike in agriculture where a small number of pests may cause a limited, tolerable amount of damage). Normally, economics are the primary consideration used to determine when to control a pest, but with microbial populations the potential for diseases and mechanical problems must be recognized. Both disease potential and system maintenance become part of the two factors that affect the economic decision-making process. These are:

Economic injury level: the level of pest density at which the cost to manage the pest is equal to the losses that the pest causes.

Economic threshold or action threshold: the level or density of a pest population where management measures (action) are needed to prevent the pest from reaching the economic injury level.

Certainly if diseases were generated in your facility, or mechanical failures occurred, these would result in economic injury.

Pest management should be considered if economic damage will occur and the population is at or above the economic threshold. Keep in mind that when dealing with aquatic-microbial control the difference between the two levels may be very slight. This is why detection is so important. Realize that, in many cases, the economic threshold for microbial pests is zero.

Remember, when making a microbial pest management decision, consider the potential for disease, the cost of the product and its application, cost of running the cooling system, the possible adverse effect of the chemical on the mechanical system, such as corrosion, and the effect this treatment may have on the environment.

SELECTION OF PEST MANAGEMENT METHODS

Once a microbial pest problem is identified, the biology of the pest understood, and the economic significance established, then the appropriate method or combination of methods can be selected to manage the pest in an effective, practical, economical and environmentally sound manner.

IPM EVALUATION

It is extremely important to evaluate the results of your pest management program. This can be done in several ways, such as monitoring pest populations or infection before and after treatment, making comparative damage ratings, etc. Visual observation, chemical testing, and bacteria cultures may be used to monitor and evaluate the effectiveness of treatments.

Keeping records of and knowing the operating history of a water processing system serves as a guide to selection of pest management tactics. Records can show the extent to which biological growths have occurred and the type of chemical controls used, if any, and their effectiveness.

Records may also provide additional guidance. For example, if a cooling system serving an industrial plant leaks fluids from heat exchangers into the cooling system that provides nutrients for microorganisms, a selective biocide for a particular type of microorganism living on this source of nutrients may be required. It may also limit the biocide selection to types that do not chemically react with the products that leak into the cooling water. Lastly, evaluations and records are useful for overall equipment maintenance, i.e. correct the leak and prevent the potential for microbial growth.

Treatments for land-based pests can be evaluated by leaving untreated checks to use as a basis for comparison. In most microbial situations it is impossible to leave untreated checks. Therefore, it is important to continually evaluate the effectiveness of your treatments and overall program, and record the results from your observations and cultures for future reference.

TECHNIQUES USED IN INTEGRATED PEST MANAGEMENT

Natural and applied techniques are used to manage pests. Proper identification, knowledge of the pest's density, and understanding the environment that favors pest development allows applicators to choose the right method or any combination to manage the pest in the most economic manner.

Natural Controls are measures that check or destroy pests often without dependence upon humans for their continuance or success. Natural controls include weather, topographical features, and naturally-occurring predators, parasites, and pathogens. Humans can protect and encourage natural control in some situations, but not in aquatic, microbial environments. Cooling towers and pulp /paper processes are artificially designed and constructed, and most natural controls do not influence the microbial populations found in these systems.

Applied Controls are controlled by humans. Their use is necessary when natural controls have not held harmful pests in check. Mechanical and physical control, sanitation control, and chemical control are applied methods commonly employed in the treatment of aquatic-microbial pests. Specific applied controls used in antimicrobial integrated pest management programs will be discussed in Chapter 3.

CHAPTER TWO

PEST IDENTIFICATION

Accurately identifying pests is extremely important because different pests respond to different types of management tactics. Failure to properly identify the pest may result in wasted time, money, chemicals, and effort. Each species of plant and animal can be identified by its scientific name. Although most plants and animals also have common names, the scientific naming system is universal, assigning an organism one name to be used regardless of where it is found. This naming system categorizes organisms based on their similarities: organisms with common characteristics are placed into large groups, then subdivided into smaller groups, and finally given a name.

In this chapter you will learn to recognize some pests directly from their presence and the presence of other pests by the signs of their activity. In cooling systems, air washers, and paper plant processes, the pests are frequently too small to be seen by the naked eye. However, the effects of the pests' activity can be readily observed.

PEST DETECTION

Many of the pests discussed here belong to the microbial world. These organisms are invisible to the naked eye, no matter what their population size. Other pests when found in large numbers, such as some algae, are easily seen without magnification.

Of the microbial pests requiring magnification for identification, bacteria leave the most easily observed signs of their presence. The thick, sticky slime masses found in heat exchangers and various process equipment are usually signs of bacterial activity. The slime mass results from gelatinous excretion during the metabolic processes of certain bacteria.

Foul odor is another telltale sign of bacterial activity. In some process systems this can be so severe that entire buildings or parts of buildings must be shut down because the stench causes workers to become ill. Here again, the presence of bacteria is indicated by indirect means.

Corrosion of process equipment is linked to or caused by microorganisms in certain cases. The link may be direct when the microorganisms produce acidic chemicals in their metabolic processes. In other cases the presence of slime or other deposits create conditions favorable for corrosion to occur but the microorganism is not directly involved. The presence and in some cases the relative quantities of these pests can often be confirmed in laboratory cultures.

MICROBIAL PESTS

The pests normally encountered in cooling systems, air wash systems, and paper mills fall into a number of separate groups. Each group is represented by a variety of species. To aid your understanding of these organisms they are covered in general terms only. Microbiological pests include viruses, bacteria, algae, mold, fungi, and slime associated with these organisms.

Viruses are obligate, intercellular parasites. This means they can only multiply in the cells of another organism (host). A viral occurrence in a building's water system is limited to the times when other pests are in that same system.

Bacteria are single celled, microscopic organisms that lack chlorophyll. Bacteria are a diverse group. Cells may be rod-shaped, spiral, or spherical and may occur singly, in pairs, or in large groups. They reproduce by division. Different strains of bacteria are adapted to a wide range of environments, including temperature, pH, oxygen availability, etc. Some bacteria require air (aerobic bacteria) while others grow only in the absence of air (anaerobic bacteria). *Legionella pneumopkila* and related organisms are small aerobic bacilli. There have been, thus far, approximately twenty species of *Legionella* described. Some of these are responsible for what is commonly known as Legionnaire's Disease.

Many of the problems found in water systems can be traced to the direct or indirect result of bacterial activity. Bacteria grow in any water that contains organic matter or certain inorganic compounds that serve as nutrients. Many of the bacteria surround their cells with slime deposits. All cooling water bacteria will grow in a temperature range of 68-104°F, and some species will grow in a broader temperature range of about 50-158°F. The aerobic slime-forming bacteria normally require a pH range of 4 to 8 and favor about 7.4. Aerobic spore-forming bacteria have a slightly narrower pH range of 5 to 8.

Because microorganisms are so widely distributed in nature, some enter cooling systems with the makeup water. However, the bulk of bacteria found in open cooling water systems are scrubbed from the air that passes through the evaporative cooling device. The slimes developed from microorganisms also serve to bind other suspended matter, such as air-borne dirt, corrosion products, and scale. This sometimes has the effect of causing a rapid accumulation of deposits under circumstances where none would have formed had there not been some microbiological growths.

In a number of industrial processes, such as the extrusion of aluminum, cooling water becomes contaminated with lubricants or other organic materials used in the process. In other cases where the cooling water is used in the scrubbing of air discharged from a process, organic materials may be dissolved in it. Bacterial growth is frequently accelerated because of the presence of such organic materials and can then cause odors in a cooling tower as described above.

Algae are very simple plants without roots, leaves, or stems that grow in aqueous environments. Algae contain chlorophyll, a green pigment, and produce their own food from water, air, and sunlight by a process known as photosynthesis. One celled algae are invisible to the naked eye but may form long strands of cells. The masses of algae which occur in improperly treated cooling systems are clearly visible.

Algae masses cause problems by directly inhibiting water flow and heat transfer. In all types of water cooling equipment algae have a habit of breaking away from surfaces of original growth, moving about in the water and then attaching to other surfaces where they grow and expand further. Algae may deposit in pipe lines to cause congestion and clogging. They may clog strainers and nozzles. On heat transfer surfaces algae can create an insulating effect impeding heat transfer, thereby reducing the efficiency of the equipment. Typically, algal growth appears on a cooling tower distribution tray, fill, screens, and drift eliminators.

Indirect effects of algae are corrosion of processing equipment and enhancement of the aquatic environment in a way that allows other microorganisms to flourish.

Most forms of algae can be grouped into four classifications based on their pigmentation or color. These groups are:

1. *Green algae* - green to yellow-green, colored by chlorophyll.

2. *Blue-green algae* - blue.

3. *Diatoms* - brown to light green, contain silica in their cell walls.

4. *Pigmented flagellates* - green to brown.

Most algae grow best in the pH range of 5.5 to 9.0. Green algae grow best in the temperature range of 86-95ºF; blue-green algae 95-105ºF; and diatoms at a range of 64-96ºF.

Fungi are saprophytes or parasites. They are a diverse group of plant-like microorganisms that, like algae, have no roots, stems or leaves, and require moisture and oxygen for growth. Because of their oxygen requirement they are generally found at or above the water line in a cooling system. Fungi differ from algae in that they contain no chlorophyll or other pigments. They are a pest of greatest concern in systems where wood is used as a material of construction or where the process involves wood and wood by-products. Cooling systems may develop either or both of the two groups of fungi: filamentous fungi or molds, and yeasts.

The filamentous fungi are made up of colorless groups of cells arranged end to end that reproduce by spores. The color of the molds is due to the black, gray, brown, tan, blue, green, or pink color of these spores. Molds are often found on the wood components of systems where they can cause surface rot or internal decay. The filamentous fungi generally grow in the pH range of 2 to 8, with 5.6 the optimum, and in a temperature range of 32-100ºF.

Yeasts require about the same conditions for growth as the filamentous fungi or molds. They are similar structurally to bacteria, but they are longer and reproduce by budding. They can produce leathery or rubbery growths which may be colored.

Slime formations consist of a gelatinous mass stemming from growth of a microorganism. Slime frequently contains physically or mechanically entrapped insoluble (will not dissolve in water) matter, organic or inorganics.

Slime and algae in cooling systems are sometimes mistakenly handled as though they were the same problem. This is not the case. Algae, which require sunlight for their growth, can often be easily prevented by installing an opaque cover on a cooling tower distribution basin. This preventative action has no effect upon the formation of bacterial slimes in the system.

OTHER PESTS

Other pests in water systems include invertebrates such as protozoa, insects, and mollusks.

Protozoa are small, complex single-celled organisms capable of living in a wide variety of aquatic environments.

Insects are normally present in water processing systems only when they are caught in the water handling system during its operation. Midges (types of tiny flies) , however, may invade and establish themselves in water treatment facilities (both equipment and ponds) and in water storage and distribution systems. Midge larvae, often called bloodworms because some of them are red, may even pass through tap water. Adult midges may emerge in huge numbers from natural or man-made bodies of water and become nuisance pests due to their presence alone or because they clog equipment and soil property, or because they stimulate allergic reactions in some people. In such conditions, midges may need to be controlled in the water systems where the adults originate.

Larval (immature) midges are aquatic and inhabit the deep zones of water where there is a sand or mud bottom. At the bottom of a water body, larvae feed on various organic materials, bacteria, and algae. Midges are particularly tolerant of poorly oxygenated and polluted conditions and are common in wastewater lagoons.

Larval midges can be controlled through the use of insecticides or by physical modification of the habitats. In wastewater treatment ponds and lagoons, water may be drawn down to expose and strand the larvae. In water delivery systems, larval midge control is difficult. Although many kinds of animals (insects and fish) prey upon midge larvae, their use as biological control agents is limited and of little practical value in a water treatment system. Among the choices for midge control, insecticides directed against the larval stage will yield the most practical results. There are limited insecticides available for this type of application. Consult with a specialist and follow all label directions.

Mollusks are a group of aquatic animals with soft unsegmented bodies and are usually, but not always, enclosed in a shell. Snails and leeches are members of this group. Mollusks contribute to water processing equipment problems by restricting water flow in service lines and plugging flow in smaller lines. The widely publicized exotic zebra mussel is a mollusk pest in Michigan.

Vertebrate pests include birds and rodents. They don't live in the water systems, but commonly die in the systems if they become trapped. Birds cause problems when droppings and nesting materials enter the water systems. Some rodents cause the same problems, but birds are usually the greater pest.

OCCURANCE OF PESTS

Occurrence of various pests in cooling systems, air wash systems and paper mill waters is widespread, though not universal. Viruses tend to be uncommon in all systems. Bacteria are the most common and nearly universal in their occurrence, whereas algae are common particularly in open recirculation cooling systems.

Fungi are found in systems using wood as a material of construction and in paper mill operations, as well as other operations using wood and wood by-products. Invertebrates can become trapped in many systems, but cause genuine problems mostly where water is drawn from lakes or streams through service lines. Vertebrates contribute to problems of equipment operation, but only to a small degree.

IMPACTS OF PESTS

Pests directly or indirectly effect the efficiency and longevity of the mechanical systems in which they occur. In virtually every instance the impact of their presence is negative.

Bacteria frequently generate slime as a part of their metabolic process. This slime reduces water flow rates through the system and reduces heat transfer across the slime-covered boundary. In addition, the slime can create an environment favorable for the development of additional pests.

In addition to the formation of deposits, bacteria frequently contribute to the corrosion process of equipment either directly or indirectly. The products of metabolism of some bacteria are acidic and hence corrosive. In other cases the bacteria may breakdown the pipe's corrosion inhibiting coating, rendering the system unprotected.

Algae are largely responsible for the visible masses of material which can effect water flow through a system. Algae may also produce an environment encouraging the growth of other pests.

The impact fungi has on water treatment systems includes the degradation of system components and, in the case of paper mills, the degradation of product quality.

The impact of invertebrates includes the plugging of system water passages. Once plugged, various forms of corrosion can and do occur in these systems. Invertebrate pests can cause heat transfer to drop to zero in plugged areas.

PROBLEMS CAUSED BY MICROORGANISMS IN INDUSTRIAL WATER PROCESSING EQUIPMENT
Restricted Water Flow
Impeded Heat Transfer
Binding Site for Other Deposits
Corrosion
Degraded Cooling Tower Wood
Potential Health Hazard
Clogged Nozzles and Strainers

CHAPTER THREE

MICROBIAL PEST MANAGEMENT

As in other areas of pest control, an integrated approach using several methods to control microbial pests is favored over reliance on simply using pesticides. Physical and mechanical controls and proper sanitation are crucial aspects of microbial pest management.

Physical and mechanical controls are usually preventative in nature. The goal is to prevent the spread of or reduce the infestation by pests using physical or mechanical means. An example of a physical control is the installation of sunlight covers on a cooling towers' distribution pans to prevent the growth of algae. Other examples include:

- Using screens and air filtering devices to keep insects, birds, and debris out of cooling towers

- Locating towers away from air intake or discharge vents (in both of the earlier mentioned *Legionella* outbreaks the bacteria were introduced through the air intake vent)

- Locate towers with consideration to the prevailing wind and away from sources of debris

- Use side stream filters to remove dirt

- Shading cooling tower decks to reduce growth of green algae

The use of ultraviolet (UV) radiation to kill microbial organisms in some cooling or process systems is an example of mechanical control. UV radiation can kill vegetative cell bacteria, but not fungal and bacteria spores. UV radiation does not penetrate well and, therefore, may not kill microorganisms which are either in clumps or covered by dust and other debris.

Sanitation is an important aspect of pest control. Sanitation includes clean-up measures to prevent breeding sites and eliminate food supplies.

Cooling towers are air scrubbers. Because of the function and design of cooling towers, any and all of the debris in the air will be washed into the tower system. The use of filtering systems of many different types helps remove this debris while the tower is "on-line." Periodically the tower should be taken "off-line" and the basin or sump cleaned of debris. Removing debris eliminates a major source of food for microbial organisms that infest towers. It also removes the deposit layer that other organisms require for their development and spread. The sludge or deposits that accumulate may require the use of a shovel and wheel barrow for removal. The sump and/or basin area of cooling towers should be inspected monthly and thoroughly cleaned twice per year.

When planning and designing a system, provide convenient access, hose connections, and drains for physical removal of algae and slime accumulations from cooling towers, and backflush connections for their removal from heat exchangers. This structural planning is important for systems in which there is a good chance for biological problems to develop, such as those in which sewage treatment plant effluent is used for makeup water.

Environmental control includes keeping the system water:

- as clean as possible

- moving at maximum rates consistent with system design

- free of particles which can settle to form deposits

Areas of low flow and stagnant water are associated with the growth of many undesirable organisms, including those responsible for Legionnaire's Disease.

Basins of cooling tower equipment may have low water flow areas with surfaces favorable to microbial growth including the fill, concrete corners, structural supports and screening. The best and most effective control is to maintain maximum allowable flow rates in the system. Operating systems at the maximum flow rate of the equipment and routinely removing deposits reduces the number of places where undesirable microorganisms can grow.

PESTICIDES

Chemical controls include naturally derived or synthetic chemicals called pesticides which kill, repel, attract, sterilize, or otherwise interfere with normal behavior of pests. When dealing with pesticides, many of the chemicals will have the suffix "cide" or "cidal" that means to kill. Biocides are the specific group of pesticides used for managing microbial pests. Examples of biocides:

Algaecides kill algae.

Bactericides kill bacteria (but not ordinarily bacteria spores).

Fungicides kill fungi (including yeast).

Slimecides kill slimes.

A related example would be sanitization (reducing the number of organisms to safe levels as determined by public health requirements) of potable water systems by using chlorine.

Biocides are typically used in an on-going microorganism management program. When biocides are used to clean-up severe infestations of algae or slime, manual cleaning may be necessary to remove the destroyed organisms from the system. The use of biocides in microbial pest management is discussed in detail in the next chapter.

CHAPTER FOUR

BIOCIDES

Biocides are a mixed blessing. They significantly contribute to the cleanliness of cooling tower water and to improved public health by managing disease-carrying organisms. But biocides can adversely affect people, nontarget organisms such as fish and wildlife, and the environment if not used according to the label directions.

In the microbial pest management industry the terms biocide, microbiocide, bactericide, and algaecide are used interchangeably even though bactericide and algaecide represent the specific control of bacteria or algae. This manual uses the general term biocide. The term biocide represents the management of all microorganisms and does not specify or distinguish between bacteria, algae, fungi or slime.

A biocide that has the ability to kill or inhibit more than one type of organism, e.g. bacteria and algae, is considered a **broad spectrum** biocide.

These terms indicate that the intended target organisms are not necessarily the only organisms affected by the chemical used. For example, in very contaminated cooling tower water, single-celled animals called protozoa are sometimes found. Applying a bactericide may kill protozoa, algae, fungi as well as bacteria.

HOW BIOCIDES WORK

The way biocides react, or their "mode of action" is often unknown. However, listed below are several mechanisms which are believed to explain the way some biocides function:

1. Protein denaturation
2. Enzyme inhibition
3. Cell membrane disruption

Biocides are often grouped based on their chemistry. There are two main categories of biocides, **oxidizing** and **non-oxidizing**.

Oxidizing Biocides are characterized by their ability to oxidize, or "burn," biological matter, such as the cell membranes of microorganisms. Since they are indiscriminate in this action, oxidizing biocides are broad-spectrum. Examples of oxidizing biocides include halogens (chlorine and bromine), ozone, and halogen-releasing compounds.

When chlorine or bromine are added to water, they react with the water and form active hypochlorous acid or hypobromous acid, respectively. These hypochlorous (HOC1) and hypobromous (HOBr) acids are the active forms of the biocide compound. They attack many components of the microbial cell with their oxidizing power. The chemistry of bromine is similar in many respects to the chemistry of chlorine.

Since HOCI and HOBr are acids, they can be neutralized with alkaline materials and their effectiveness decreased. These acids are said to be pH sensitive. As the pH of the water increases (becomes more alkaline), the effectiveness of chlorine and bromine decreases.

A pH reading is a measure of the acidity-alkalinity relationship. The pH scale ranges from 1 to 14, with 7 being neutral. Anything with a numerical value less than 7 is said to be acidic and a numerical value greater than 7 is considered alkaline.

Chlorine and the chlorine-yielding compounds behave chemically in essentially the same way. When added to water they form a mixture of hypochlorous acid and hypochlorite ion. The microbiocidal effectiveness of chlorine and chlorine yielding compounds depends upon the proportion of hypochlorous acid present which, in turn, depends upon the pH of the treated water. The table below outlines the percent of active and inactive forms of HOC1 and OC1based on the pH of the treated water.

H+	HOCI	OCI-
Hydrogen Ion	Hypochlorous Acid **Active**, Unstable Form	Hypochlorite Ion **Inactive**, Stable form
pH of water	**%Chlorine as HOCL**	**%Chlorine as OCI**
6.5	90	10
7.0	75	27
7.2	66	34
7.6	45	55
8.0	23	79
8.5	10	90

Chlorine can react with organic compounds, ammonia, and other materials present in water so its microbiocidal activity depends upon the residual chlorine available after the chlorine demand of the water has been satisfied, rather than on the dosage of chlorine applied to the water. Chlorine also reacts with the components of wood so that concentrations in excess of one ppm can delignify (degrade) the tower wood, shortening the life of the equipment.

Chlorine in solution is relatively unstable. It can be decomposed by the action of ultraviolet light to which it is exposed in the top decks of cooling towers. Some of it is lost by volatilization each time that the water passes through the sprays or over the fill in a tower.

A thorough review of cooling water chlorination appears in G. C. White, *Handbook of Chlorination,* Chapter 9, "Chlorination of Cooling Water", pages 527-571, (Van Nostrand Reinhold Company, New York, 1972).

Chlorine, chlorine-yielding compounds, and other oxidizing biocides are effective for controlling virtually all cooling water microorganisms.

Non-Oxidizing Biocides can be subdivided into one of several categories including;

- quaternary ammonium compounds
- organosulfurs
- halogenated organics
- aldehydes

Many non-oxidizing biocides are broad-spectrum, as indicated on the label. The quaternary ammonium compounds represent one of the largest groups of non-oxidizing biocides used for cooling water treatment. They are generally effective in managing most algae and bacteria.

Quaternary ammonium compounds may be included in water treatment formulations as single compounds, as mixtures of several quaternaries, or as mixtures with other types of pesticides. Depending upon the structure of the quaternary ammonium compound, its effectiveness as a biocide can be reduced by the presence of specific materials in the cooling water, such as hardness, high dissolved solid concentration, or organic matter. Excessive dosages of most quaternary ammonium compounds can cause undesirable foaming in the cooling water.

A number of organosulfur compounds are in use, alone or in combination, in cooling tower biocide products. These are used primarily as bactericides.

BIOCIDE FORMULATIONS

Biocides are available in a number of different formulations (pesticide formulations are covered in detail in Unit 3 of *Applying Pesticides Correctly*). It is important to choose a biocide formulation that is best suited for a particular job based on its effectiveness, cost, practicality, and relative safety to you and the environment.

Dry Formulations of biocides are generally available in either granular or tablet form. Many of the tablets dissolve slowly and need special feeders to get them dissolved. This does have an environmental advantage in that only a controlled small dosage can go into the water at any one time. Probably the majority of dry formulations are chlorine or bromine releasing types. Powdered, water soluble biocides are available packaged in premeasured, water dissolvable bags that can be put into the sump of cooling towers without allowing the chemical to contact the applicator. Gloves should be worn when handling these products.

Most biocides are available as **liquid formulations**. In this industry liquids are considered more convenient to use than dry formulations. Some biocides are manually added to systems. Liquids can be pumped directly from the shipping container. Direct pumping and metering provides a safe and practical way of applying biocides, especially for larger systems and cooling towers located on building roofs. The applicator pump can be wired through a timer to allow for controlled dosages at specified intervals.

BIOCIDE ADJUVANTS

An adjuvant or additive is a chemical added to a pesticide principally to increase its effectiveness, such as the stabilizer added to the dry chlorine-releasing formulation mentioned above. Other compounds might be included in a biocide formulation to increase the water solubility of the formulation. These compounds may be listed as one of the active ingredients, or considered part of the inert ingredients listed on the label.

These biocide adjuvants are already present in the formulation as purchased from a supplier. No adjuvants or any chemicals should ever be added to a packaged biocide unless specifically mentioned on the label. This may be allowed by some agricultural pesticide labels but is seldom allowed with biocides.

Biocide adjuvants, however, can be *separately* added to a system. The amount of biocide needed is often dependent on the cleanliness of a system. The cleaner the system the less biocide needed to obtain a desired result. Low molecular polymers and surfactants can be used to clean and disperse particles, allowing the biocide to reach the microorganisms. High molecular polymers have also been used to flocculate contaminants in a flowing system allowing the force of the water to push the flocculated material out of the system.

COMPATIBILITY

Never mix two concentrated formulations of biocides together. When an amount of biocide already exists in a very large volume of water, as in the case of a cooling tower system or a swimming pool, other chemicals may be added as long as significant dilution occurs and it is not prohibited by the biocide label. (In this case we may be talking about 1 gallon of biocide added to 10,000 gallons of water). In spite of these recommendations and precautions, compatibility problems may still occur among biocides and other chemicals that may be in the same system.

A case of **physical incompatibility** may occur when two different biocides are pumped into a cooling tower and somewhere before the chemical actually enters the system, a common feed line is used. This is a typical example of how two concentrated chemicals might be mixed, commonly resulting in a plugged feed line.

Chemical Incompatibility. The practice of using one pail to transfer a biocide from a shipping container to the water system can lead to unexpected fireworks. Normally, two biocides are added one at a time to a water system. If the pail used for the transfer is not clean, the next biocide can react with the remains of the previous biocide in the pail. Depending on the biocides involved, explosions and fire can result. This most often occurs when a strong oxidizer, such as a chlorine-containing biocide, reacts with a readily oxidizable organic biocide. Designate different pails for different products and triple rinse the pails between uses and products.

By pumping and metering biocides directly from the shipping container into the system being treated, the risk of exposure and the incompatibility problem described above is reduced.

Timing Incompatibility. Microorganisms are most susceptible when they are actively growing and reproducing. Biocides should be added before the microbiological population overwhelms the system. Microorganisms increase their growth rate as water temperature rises. This means that an applicator must be alert to changing weather conditions, especially in the spring as temperatures go up. Monitor the water system more frequently during high temperatures.

Incompatibility With Corrosion and Scale Inhibitors. Incompatibility may also exist between a biocide and other chemicals in a system such as corrosion and scale inhibitors. Biocide formulations used in a particular cooling system must be compatible with these other treatments and with the materials of construction of the cooling water system itself.

For example, if the cooling water system is being treated with a corrosion and scale inhibitor program so that the circulating water has a pH of 8.0 or above, avoid using a biocide that has a very low efficiency or that decomposes in this pH range. Likewise, do not use an oxidizing biocide when one of the other treatment chemicals is readily oxidized. Technical sales representatives should inform you of any potential problems.

This has been a brief summary of the problems of biocide compatibility. Remember, you should never assume that biocides can be mixed together or mixed with another chemical unless the combination is specifically indicated on a product label.

DOSAGE

The dosage of a biocide is based upon the cleanliness of the system and whether an initial treatment or a maintenance treatment is intended. Dosages for each purpose are given on biocide labels. The initial dosage may be higher than a maintenance dosage. This is because the initial treatment is to reduce the existing count of microorganisms in the water to an acceptably low level, after which a lower dosage of biocide can be used to maintain this level. Use the lowest possible dose required to obtain the desired effect. This practice reduces the potential for a pest to build resistance to a specific chemical. Never use a higher rate than is recommended on the label.

Another critical factor in connection with the initial use of a biocide is the physical cleaning of the system to remove, as much as possible, existing deposits of microorganisms. The slime sheaths that many bacteria and fungi surround themselves with protect the organisms against contact with biocides. Therefore, when there is less accumulation of slimes and algae in a cooling water system, any given dose of biocide is more effective in reducing the total population of the organisms.

FREQUENCY

The frequency of treatment, as well as the dosage, depends upon the microbiological population in the water system, the cost of treatment, other related equipment operating considerations, health concerns, and the action threshold as determined by users of the system. In oncethrough systems, the large volume of water flow may make continuous treatment very expensive. Therefore, chlorination or treatment with chlorine dioxide may be carried out for a half hour to an hour from one to four times daily. Treatments with other types of biocides in cooling towers may vary from as frequently as once a day to as little as once a month, depending upon the need as shown by standard plate counts of organisms in the water or by the appearance of slimes or algae at certain observation points in the system.

CONCERNS

Careless biocide use can create microbiological resistance and may harm nontarget species. The following sections explain precautions applicators can take to avoid these problems.

Microbiological Resistance. Microbiological growth and reproduction can be very rapid. Biocides are therefore added to water systems frequently. Depending on the product, biocides may be added once every two weeks in colder weather and three times a week in hot weather in the case of cooling tower applications. Swimming pools require even more frequent applications. Thus, the faster the growth of the microorganisms, the more frequent the application of biocides and the greater the possibility for the microorganism population to develop resistance.

Cross and multiple resistance to some biocides are common. **Cross resistance** is when a microorganism develops resistance to two or more compounds that are usually chemically-related with a similar mode of action. **Multiple resistance** occurs when a microorganism can tolerate biocides from different classes of compounds with unlike modes of action.

Reducing the problems of resistance involves using new or altered biocides, and changing the use patterns of biocides.

New or Altered Biocides. Single compounds or mixtures of compounds that have more than one mode of action are usually more difficult for the microorganism to develop resistance to than compounds that attack only one chemical site in or on the microorganism. New compounds with different modes of action will also lessen the likelihood of resistance development, at least for a time.

Biocide Use Patterns. Rotating the use of biocides with different modes of action limits the occurrence of pest resistance. When a biocide is added to a system, it is possible that 99.9% of the organisms are killed or inhibited. As time goes on, the few remaining microorganisms (which are the most resistant in the population) begin to multiply. The microbial population has the potential to become almost completely composed of organisms resistant to the product originally used. Avoid developing a resistant population by alternating the type of biocide and use biocides having different modes of action.

Dosage is also important in avoiding pest resistance. Use the lowest rate of biocide that will achieve the desired level of microbial control.

Managing pest resistance is a part of integrated pest management. Resistance must be understood, detected at low levels, and managed by using all of the available techniques to extend the useful life of our current biocides.

CHAPTER 5

BIOCIDES AND THE ENVIRONMENT

As our population continues to grow, so do our demands for clean water and air and an environment that is not threatening to our health and safety. We have become increasingly concerned about the condition of our environment. We worry that the earth's natural resources are not only being depleted, but also becoming polluted and unfit for human use. As a result, many of the activities that we have taken for granted are now being carefully examined for potential damage to the environment. Pesticides are one group of chemicals being blamed for environmental abuse.

Pesticides include the biocides that are used to control pests in cooling towers, pulp and paper mills, evaporative condensers, and other water processing equipment. Cooling towers are used to remove heat from industrial processes, commercial and institutional buildings.

This chapter explores what happens to biocides after application. You will learn about groundwater and how it can be contaminated. We will discuss the effects of biocides on non-target organisms and the environment. For our purposes, environment means all of our physical, chemical and biological surroundings such as climate, soil, water, and air and all species of plants, animals, and microorganisms.

CONTAMINATION

Groundwater Contamination. Groundwater is the water found below the earth's surface occupying the saturated zone, that is, the area where all the pore spaces in the rock or soil are filled with water. It is stored in water-bearing geological formations known as **aquifers.** Groundwater moves through aquifers and can be obtained at points of natural discharge such as springs or streams, or by drilling a well into the aquifer.

The upper level of the water-saturated zone in the ground is called the **water table.** The water table depth below the soil surface fluctuates throughout the year, depending on the amount of water removed from the ground and the amount of water added by recharge. **Recharge** is water that seeps through the soil from rain, melting snow, or irrigations.

Surface waters are visible bodies of water such as lakes, rivers, and oceans. Both surface water and groundwater can be contaminated by **non-point source pollution.** This type of pollution generally results from land runoff, precipitation, acid rain, or percolation rather than from a discharge at a specific, single location (such as a single pipe). Non-point source pollution occurs when the rate at which pollutant materials entering water bodies or groundwater exceeds natural levels. Contamination from discharge at a single location (such as a single discharge pipe from a factory) is **point source pollution.** A cooling tower is an example of a potential point source pollution.

Cooling tower operations provide the potential for chemicals used as water treatment additives to enter the environment. Biocides can escape the cooling tower equipment by evaporating and as drift. Evaporation is water loss from the circulating water into the atmosphere by the cooling process. Also, water containing biocides can be lost by drift; liquid droplets transported with the exhaust air.

Another way chemicals in cooling towers and boilers can enter the environment is through **blowdown.** Blowdown is the water discharged from the cooling tower or boiler system. Blowdown may also be called bleedoff. Reasons for blowdown procedures include controlling the concentration of salts and/or other impurities in the circulating water.

Constraints continue to be imposed on the treatment of microbial organisms in water systems as a result of pollution control regulations and water conservation measures. The latter has led to operating systems at higher cycles of concentration which increases the concentration of nutrients in the circulating water, particularly in some industrial environments such as ammonia plants. At the same time, pollution control regulations limit the toxicity to aquatic life of any blowdown discharged to a river, lake, or surface water. Here we must face the paradoxical requirements for biocides: they must be toxic to the undesirable organisms in the cooling water, but also be non-toxic to organisms, large and small, that live in the water to which the blowdown is discharged. In some cases the receiving water of blowdown may be a biological wastewater treatment plant, in which case the biocide must kill undesirable bacteria in the tower but not be harmful to useful bacteria in the wastewater treatment process. The importance of considering the total cooling water system - water source, water and air conditions in the recirculation loop, and the system receiving the blowdown - when selecting and implementing a water treatment cannot be over emphasized.

The potential for groundwater pollution from improper agricultural and industrial practices is a significant concern. Pesticide residues, in particular, are receiving considerable national attention. The microbial pest management industry must use safe and environmentally sound practices to avoid contributing to contamination problems. Blowdown water needs to be managed appropriately so biocide residues do not enter the environment and harm non-target organisms.

PESTICIDE AND BIOCIDE FATE

As discussed in the last chapter, biocides are pesticides used for managing microbial organisms. It is important to understand the behavior of chemicals used as pesticides once they have been applied according to label directions. We will describe some of the processes that change or influence the availability, effectiveness, structure, or physical identity of chemicals used as pesticides.

When a pesticide is released into the environment it is affected by various processes. Sometimes these processes are beneficial. For example, pesticide degradation can remove nonessential biocide residues from the environment. The leaching of a root-absorbed herbicide into the root zone can enhance weed management. However, some processes can be detrimental. Runoff can move pesticides away from target sites and pests. As a result, chemical is wasted, control is reduced, and there is an increased chance of damage to nontarget plants, hazard to human health, and pollution of nearby soil and water.

Adsorption is the binding of chemicals to soil particles. The amount and persistence of pesticide adsorption varies with pesticide properties, soil moisture content, soil acidity, and soil texture. Soils high in organic matter or clay are the most adsorptive; coarse, sandy soils that lack organic matter or clay are much less adsorptive.

Biocides are intended for application to water treatment systems, not as soil applications. Biocides may come in contact with soil when a water system is purged and the released water contains residual biocide concentrations. At this point, the soil environment will have an affect on the persistence of a biocide in the environment.

Absorption is the process by which chemicals are taken up by plants, animals, humans, or microorganisms. Absorption is another process that can transfer biocides and other pesticides in the environment.

Volatilization occurs when a solid or liquid turns into a gas. Volatilization of chemicals increases with higher air temperature and air movement, higher temperature at the treated surface (soil, plant, etc.), low relative humidity, and when spray droplets are small.

A pesticide in a gaseous state can be carried away from a treated area by air currents; the movement of pesticide vapors in the atmosphere is called vapor drift. Unlike the drift of sprays and dusts that can sometimes be seen during an application, vapor drift is invisible.

Runoff is a process that moves pesticides in water. Runoff occurs as water moves over a sloping surface, carrying pesticides either mixed in the water or bound to eroding soil. Runoff may occur after a spill, a poorly timed agricultural field or home lawn application followed by a heavy rain, or when a tower is blowndown to an inappropriate site.

Leaching is another process that moves pesticides in water. In contrast to runoff, which occurs as water moves on the surface of the land, leaching occurs as water moves downward through the soil.

DEGRADATION

Microbial Degradation occurs when microorganisms such as fungi and bacteria use pesticides as food sources. One gram of soil may contain thousands of microbes. Microbial degradation can be rapid and thorough under soil conditions favoring microbial growth. Those conditions include warm temperatures, favorable pH levels, adequate soil moisture, aeration (oxygen), and fertility. The amount of adsorption of a pesticide to soil also influences microbial degradation. Adsorbed pesticides, because they are less available to some microorganisms, are more slowly degraded.

The microbial pest management industry views fungi, bacteria and other microorganisms in water treatment systems as pests. The biocides used in these systems are designed to kill microorganisms. Therefore, this category of pesticides, biocides, is not influenced as strongly by microbial degradation as are others, such as herbicides and insecticides. Microorganisms in a water treatment system are undesirable. Yet, microorganisms in the soil and other environments can be very beneficial, acting as chemical cleanup crews.

Chemical degradation is the breakdown of pesticides by processes not involving a living organism. The adsorption of pesticides to soil, soil pH levels, soil temperature and moisture all influence the rate and type of chemical reactions that occur. Many pesticides, especially the organophosphate insecticides, are susceptible to degradation by hydrolysis in high pH (alkaline) soils or spray mixes. We also know that chlorine and bromine-based biocides are less effective or rendered ineffective at high pH levels.

Photodegradation is the breakdown of pesticides by the action of sunlight. Pesticides applied to foliage, the soil surface, or structures vary considerably in their stability when exposed to natural light. Similar to other degradation processes, photodegradation reduces the amount of chemical present, which can subsequently reduce the level of pest control. Soil incorporation by mechanical methods during or after application, or by irrigation water or rainfall following application, can reduce pesticide exposure to sunlight. Biocides in a water treatment system have limited exposure to sunlight.

LIMITING PESTICIDE TRANSFERS IN THE ENVIRONMENT

It is very difficult to purify or clean groundwater that has become contaminated. Treatment is complicated, time consuming, expensive, and often not feasible. The best solution is to prevent the groundwater contamination problem. The following biocide applicator practices can reduce the potential for surface and groundwater contamination.

- Select Biocides Carefully: Read labels carefully and consult your water service company or product supplier if necessary.

• Follow Label Directions: The label carries crucial information about the proper dilution rate, timing, and placement of biocides in a system. The label is the law. Follow all directions.

• Calibrate Accurately: Calibrate equipment carefully and often. During the calibration procedure, check the equipment for leaks and malfunctions. Equipment can be calibrated with water instead of the chemical to be metered.

• Measure Accurately: Concentrates need to be carefully measured before they are placed into the dilution tank. Do not "add a little extra" to ensure the biocide will do a better job. Such practices only increase the likelihood of personal injury, damage to equipment, cost, and the chance of contaminating groundwater.

• Avoid Back-Siphoning: The end of the fill hose should remain above the water level in the dilution tank at all times to prevent back-siphoning of chemical into the water supply. This practice also reduces the likelihood of the hose becoming contaminated with a biocide.

• Avoid Spills-Clean Up Spills: When spills occur, contain and clean them up quickly. Chemicals spilled near wells and sinkholes can move directly and rapidly into groundwater.

• Dispose of Wastes Properly: All biocide wastes must be disposed of in accordance with local, state, and federal laws. Instructions for triple-rinsing and power-rinsing containers are included in the pesticide storage and disposal chapter. Pour rinsates into the water treatment system. Never pour unused pesticides or rinse water into drains, sewers, streams, or other places that will contaminate the environment.

Effects On Nontarget Organisms

Applying, handling, or disposing of biocides carelessly can harm nontarget organisms that are beneficial to agriculture, our environment, and our existence. Consider what happens to the biocide after it is applied What kind of fish, fowl, and other organisms live where treated water is released? It is crucial that we know what can be safely applied and discharged and how to properly store and dispose of containers to protect these species.

Bees and Other Pollinators. Bees and other pollinating insects are essential for successful production of many crops such as deciduous tree fruits, small fruits, most seed crops, and certain vegetables. Many pesticides, particularly insecticides, are highly toxic to pollinating honeybees and wild bees. Be aware of how bee poisoning can occur and how it can be prevented.

Fish and Other Wildlife. Pesticides can be harmful to all kinds of vertebrates. Direct effects from acute poisoning are the most recognizable impacts. Fish kills often are a direct result of water pollution by a pesticide. Pesticides can enter water via drift, surface runoff, soil erosion, leaching and, in some cases, deliberate or careless release of pesticide directly into the water. Fish kills are most often caused by insecticide contamination of small ponds or streams with low water volume or turnover.

Bird kills from pesticides can occur in a number of ways. Birds can ingest the toxicant in granules, or baits, they may be exposed to pesticide drift, or they may consume contaminated water.

Environmental damage can be avoided when pesticides are used carefully, wisely and according to the instructions on the product label.

BIOCIDES AND HUMAN HEALTH

The effects of pesticides on human health are covered in detail in Unit 6 of *Applying Pesticides Correctly*. However, there are a few concerns specific to biocides used in microbial pest management.

Human exposure to toxic levels of biocides results in a variety of general symptoms and signs of poisoning. These vary with the biocide, the amount absorbed, and the general health condition of the individual. Some of the most common symptoms and signs are:

• **When a substance is touched:** skin irritation (drying and cracking), skin discoloration (reddening or yellowing), itching, or a burn.

• **When the substance is inhaled:** burning sinuses, throat and lungs, accompanied by coughing, hoarseness and upper respiratory congestion.

• **When the substance is ingested:** mouth and throat irritation, chest pains, nausea (stomach ache), diarrhea, muscle twitching, sweating, headache and weakness.

Symptoms can begin immediately upon exposure or may be delayed for several hours or even days.

CHAPTER 6

APPLICATION EQUIPMENT

A brief description of some cooling water processing equipment to which biocides are applied may help to establish an understanding of how microbial pest management programs are performed. This review of a limited range of equipment is not intended to provide you with all the information that you need for effective pest control at your specific facility and situation. Up-to-date information regarding equipment, materials and methods should be obtained from the equipment manufacturer, biocide manufacturer, reference manuals, your supervisor, professional associations and the biocide label.

Cooling water systems in industrial, commercial and institutional establishments may be open or closed. Open cooling water systems may be once-through or recirculating. All closed systems are recirculating.

Open Systems

Once-Through Systems. In once-through systems, water is taken from a river, lake, well or other source. The water is passed through a heat exchanger which extracts heat from another liquid or vapor separated from the water by a metallic barrier. The water is then discharged to the source from which it was obtained or to another surface waterway in accordance with all local and state ordinances. Large electric power generating stations are frequent users of once-through cooling systems. Because of the large quantities of water needed for once-through cooling and the effects of the warmer discharge water on the wildlife of receiving streams, the use of once-through cooling water systems is being sharply restricted, and most cooling water systems are now recirculating systems.

Recirculating Systems. Depending upon the nature of the cooling requirements, open recirculating cooling water systems may include cooling towers, evaporative condensers, or evaporative coolers to reduce the water temperature. Although each of these types of recirculating cooling water equipment differs somewhat from the other in form or operation, the basic principles involved are the same. Cooling water is passed through a heat exchanger as described above for once-through systems. However, instead of discharging the warmed water to waste, it is circulated through an evaporative cooling device in which the evaporation of a small portion of the water absorbs enough heat so that the remainder of the water is cooled to its original temperature. The cooled water is then circulated through the heat exchanger again. Water lost by evaporation is replaced by makeup water from a river, lake, well or city water supply and the cycle is repeated indefinitely.

Cooling towers for air conditioning systems are commonly designed to evaporate 1% of the circulating water, thereby absorbing enough heat to cool the remainder of the water by 10°F. Industrial cooling towers frequently operate with higher evaporation rates (2-4%) and somewhat higher temperature differences.

Operational Concerns With Open Cooling Water Systems

Salt Concentration. The process of evaporation can concentrate salts present in the water to a point where they can form scale on the equipment, which reduces cooling capacity. Further buildup of deposits in piping reduces water flow and increases pumping power requirements. To avoid scale and deposit formation, cooling waters are treated with deposit-inhibiting chemicals and a small portion of the circulating water is discharged as waste to limit the concentration of dissolved solids. This discharge is known as blowdown or bleed-off (described in Chapter 5). The blowdown rate depends on the cooling tower chemistry and may range from as low as 0.25%, up to 3 or 4% of the circulation rate. For reasons of water and energy conservation and economy of waste water treatment, the trend is toward low blowdown rates.

Deterioration. Oxygen absorbed from the air as the water falls through a cooling tower promotes corrosion of metallic portions of the cooling system. Other impurities can accelerate corrosion or cause more dangerous localized corrosion or pitting. These processes eventually lead to leaks that require replacing portions of the system. Still other impurities can cause the cooling tower wood to deteriorate.

Biological Growths. Organic impurities, including bacterial slimes and other microbial growths, can accelerate deterioration of equipment. They can also cause odors and, in extreme cases, create potential health hazards should pathogenic organisms be discharged to the air from evaporative cooling equipment. In addition, the growth of microorganisms in cooling waters seriously interferes with cooling tower system operation and life. Heavy formation of algae can clog spray nozzles and distribution decks and form deposits on heat exchange surfaces. The slimes developed from bacteria and fungi can do the same and also serve to bind other suspended matter, such as airborne dirt, corrosion products, or scale. This rapidly accelerates the buildup of deposits and sometimes causes deposits to accumulate under circumstances where none would have formed had there not been some microbiological growths present.

These deposits reduce heat transfer and thus increase energy requirements. Tests show that a 1 mil (0.001 inch) thick deposit of slime reduced overall heat transfer by about 10%, and 20-50 mil deposits reduced heat transfer by as much as 40%. Corrosion is frequently accelerated and localized beneath microbiological growths. For these reasons, it is important to treat cooling tower water with biocides to manage growth of microorganisms.

Closed Recirculating Systems

In closed recirculating cooling water systems, the cooling water picks up heat from a heat exchanger as described above for open systems, but this heat is removed by passing the water through a second heat exchanger in which the water is cooled by a flow of cooler water or air on the other side of a metallic barrier. There is no evaporation of water.

Comfort cooling system including a free cooling mode. Central air conditioning systems are an example of a closed circuit. Heat is absorbed from the air into chilled water in an air-to-water heat exchanger. The water then circulates to a refrigeration machine which absorbs this heat and recools the chilled water which is then returned to the air-to-water heat exchanger. Closed recirculating cooling water systems develop problems which require applying a pesticide less frequently than open systems.

BIOCIDE APPLICATION

Aquatic-microbial pesticides are usually applied as either a liquid, spray, or a compressed powder (pellets or tablets). The pesticide feed equipment must be matched to the pesticide material as well as the size and type of job. Choosing appropriate application equipment and operating and maintaining it properly is as important to effective pest management as selecting the pesticide. To make an effective, safe, and efficient application, the equipment must be properly selected, operated, calibrated, and maintained.

Normally there are only three methods of applying aquatic-microbial pesticides. Liquid biocides can be added to the water in the system manually or through a pump. Liquids can also be used in a tank sprayer for special applications. Finally, compressed powders can be added via some form of manual feed or through a tablet feed device.

Application Equipment

Microbial managers use a variety of equipment to place the biocide in the system while at the same time offering safety to the applicator and environment. Common equipment is described here.

The **pump-timer method** is perhaps the most widely used and safest means to deliver pesticide into a cooling or process system. As the name implies, the application is done by a pump that is activated by a timer, usually a seven or fourteen day programmable unit. The chemical metering pump (either diaphragm or piston type) is the heart of the application system. Using the adjustments for speed and/or percent of stroke, the metering pump can be calibrated to deliver a fixed amount of liquid pesticide in a specific amount of time. The programmable timer is set so that the pump is turned on for enough time to deliver the correct dosage at the required frequency.

For example, this system can be set to deliver 15 ounces of biocide per 1000 gallons of system water every three days. It must be pointed out that the pump should be sized so that the correct dosage is delivered in a short period of time since the cooling system is also bleeding water to drain and will dilute the biocide that is available for an effective kill.

Some of these units can activate alternating pumps to supply different biocides. This practice helps to avoid development of resistant populations of organisms.

The calibration of this unit requires only a few minutes and should be checked periodically. To calibrate, flush the pump and hoses (suction and discharge) with water to remove residual biocide. Redirect the injection valve from the treated system into a graduated container (showing ounces of fluid). Manually activate the timer for a designated period of time and measure the amount of water that is pumped during this time frame. Adjust the pump settings as required to produce the correct dosage such as 20 ounces in 5 minutes.

Normally there are limited operational problems with this type of system provided that the applicator does not let the container of biocide run dry. The only maintenance on this system requires resetting the timer (if required by power loss) and checking and replacing check valves and springs as recommended by the manufacturer.

Tablets and Pellets. Tablet feeders are the safest means of introducing compressed powders into the system that requires treatment. This device holds a given weight of tablets, depending on the size of the system and the size of the feeder. The feeder is piped into the system's circulating water supply in such a way that it can be valved off for filling and valved on to allow system water to flow through the feeder. Usually the feeder has a throttling valve that allows the applicator to adjust the amount of water passing through the feeder. As the tablets dissolve, the biocide is continuously fed into the process or cooling system.

This type of unit is commonly used with oxidizers like chlorine or bromine. Caution must be taken never to leave the unit valved off with biocide and water in it because gases can develop that can explode the unit.

Calibration is done by careful monitoring of the system water for the required dosage of biocide and by adjusting the throttling valve to maintain the correct dosage.

An alternate to the tablet feeder is the use of mesh bags to suspend the compressed powders in the water of the system to be treated. The correct dosage for the volume of water being treated is placed into the mesh bags, the bags are lowered into the system water, and the system water is monitored for the required dosage of biocide. If the level of biocide goes over the proper amount, some of the biocide bags are removed from the water until the correct level is maintained. If the level is too low additional bags of tablets are added. This system is more labor intensive than is the tablet feeder.

Sprays. The application of pesticides by spray is of limited use in aquatic-microbial control. The two situations which are appropriate for using a spray application would be in the removal of infestations from cooling tower air diffusers, and for disinfecting towers, tanks, screens, slats, etc. while the system is dry and out of service. For this application a small tank sprayer with a discharge wand can be used to quickly cover the target area with pesticide. Follow the manufacturers directions for the spray tank operation and all personal protection requirements as listed on the pesticide label. Make sure that the spray tank material is not going to be effected by the type of pesticide being used, and thoroughly wash the spray unit after use. Dispose of the wash water per label directions.

Manual or Hand Feeding. Liquid pesticides can be manually applied into cooling and process systems to achieve effective pest control. Manual feeding requires accurate measurement and pouring of the correct amount of biocide into the effected system. Biocides are applied when you have identified an infestation or when the required parts per million of biocide has fallen below the maintenance level or its effective kill range. Like mesh feeding of tablets, this is a labor intensive procedure and, more importantly, exposes the applicator to the biocide more frequently (with a greater possibility of spillage, personal injury, or damage to the environment) than does an automatic system.

PRECISE APPLICATION OF BIOCIDES

Biocides must be applied to process or cooling systems according to all label instructions. All applications are measured in either ounces per gallons treated (example: 4 to 20 oz per 1,000 gallons of system water), or in parts per million (ppm) of product in the system water. To safely and legally apply the biocide, the applicator must know the volume of water that is going to be treated.

Determining System Volume

The most simple and accurate method for determining the volume of a cooling system or water bath in a pulp mill is to drain the system and refill it using a water meter on the make-up water supply are before and after readings of volume with the water meter. Many of these systems are drained seasonally or for periodic maintenance. Installing a meter on the fill line will provide not only information about the systems' volume but can be used for chemical feed and to provide a continuing record of actual water use.

Geometry or standard tables of measurement can be used quickly and easily to determine the volume of water in a system being treated. For example, if a closed recirculating system requires sanitizing with chlorine, direct measurements of pipe size and total length of pipe in the closed system can be taken to determine the system volume and the necessary amount of chlorine. Tables of standard measurement (such as Water and Waste Treatment Data Book, compiled by the Permutit Co.) provide the number of gallons of water per foot of pipe. If air separators, expansion tanks, or tower basins are involved, you can size these from the standard tables or use geometry to determine the equipment's volume and multiply by 7.48 to convert the volume of water in cubic feet to gallons. Some of the most commonly used formulas and constants are listed here:

Tank Volume:

Rectangular = Length X Width X Height

Cylindrical = π X r^2 X Height

π = 3.14, r = radius
7.48 gallons per cubic foot of water
8.34 pounds per gallon of water

Pipe Size (inches)	Gallons per Foot
1	0.05
2	0.16
4	0.65
6	1.47
8	2.61
10	4.08
12	5.88
16	10.44
18	13.22
20	16.32
24	23.50
30	36.72
36	52.88

Another method of determining the volume of a system is the use of a salt test. This salt test method is also used in systems where the calculations of pipe and equipment size are not easily obtained. To begin a salt test you need an estimate of the system volume, then follow these procedures:

1. Shut off system bleed.

2. Accurately measure the chloride level in the system.

3. Add 1 /2 pound of table salt (not rock salt) to the system for each 1,000 gallons of estimated volume. It is best to dissolve the salt in a pail, using system water, then pour the salt solution into the system. In larger systems add the salt in increments to allow it to dissolve.

4. Allow the salt solution to mix completely in the system by circulating for 30 to 60 minutes (for larger systems, circulate longer).

5. Take a chloride test every 10 minutes until the chloride level is stable. The stable level will be the "final" chloride level in the following equation.

NOTE: We are adding salt (NaCl) but only measuring for the chloride level. Chloride is approximately 60% of the salt compound which is why we multiply the pounds of salt added by .60 in the following equation. The 1,000,000 and 8.34 lbs/gallon values are part of the equation allowing us to convert ppm and pounds into the unit we need in our answer, which is gallons. See below.

6. System Volume in gallons =

$$\frac{(1{,}000{,}000) \times (.60) \times (\text{lbs. salt added})}{(8.34\ \text{lbs/gallon}) \times (\text{Final Chloride ppm} - \text{Initial Chloride ppm})}$$

$$= \frac{71{,}942 \times \text{lbs. of salt added}}{\text{Final Chloride ppm} - \text{Initial Chloride ppm}}$$

NOTE: Many operators use this calculation and round the number 71,942 found in the numerator of the equation up to 72,000. Therefore, an acceptable equation for determining the volume of a system is:

$$\frac{72{,}000 \times \text{lbs. of salt added}}{\text{Final Chloride ppm} - \text{Initial Chloride ppm}}$$

Application Rate

The amount of biocide that must be applied per system volume is stated on the label. Too much biocide can damage equipment or the environment and lead to fines for discharging higher levels than allowable; too little biocide will not achieve good control.

Biocides are applied in dosages based upon ounces of product per system volume, or ppm of product in the water.

To determine how much product to apply, multiply the amount of product needed per 1,000 gallons by the number of gallons in your system. If 20 ounces treats 1,000 gallons of water and your system holds 50,000 gallons, then:

$$\frac{20\ \text{ounces} \times 50{,}000\ \text{gal.}}{1{,}000\ \text{gallons}} \quad \mathbf{= 1{,}000\ oz}$$

If this 50,000 gallon system were to be treated with 125 ppm of product, you need to determine

the pounds of product that, when added to 50,000 gallons, would produce 125 ppm. Since ppm is pounds per million pounds in this situation, and one gallon of water weighs 8.34 lbs, use the following formula to calculate:

$$\frac{\text{Desired ppm} \times \text{System volume (gallons)} \times 8.34\ \text{lbs/gallon}}{1{,}000{,}000}$$

= lbs of product

Therefore:

$$\frac{125\ \text{ppm} \times 50{,}000\ \text{gallons} \times 8.34\ \text{lbs/gallon}}{1{,}000{,}000}$$

= 52.12 lbs of product