INSECTICIDE FORMULATIONS—TYPES AND USES: A REVIEW

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ABSTRACT. This review paper contains a brief discussion of the composition, preparation and use of the various types of insecticide formulations and is presented as an aid to persons presently engaged in mosquito control. A glossary of common formulation has also been added for the benefit of those persons not familiar with the vocabulary.

INTRODUCTION

In order for an insecticide to be effectively used in the control of insects, it must first be prepared into a form suitable for a particular application method. This preparation of an insecticide is called a formulation and involves the addition of various chemical solvents or diluents to improve the effectiveness or physical properties of the insecticide.

Most insecticides currently in use in mosquito control are sufficiently toxic to allow considerable dilution and still be effective. Formulations thus enable the relatively small amounts of active toxicant to be diluted and evenly dispersed over the treated area for maximum effectiveness. For more indepth discussions of the various types of formulations, the reader is referred to the references at the end of this article.

Since the description of the types and preparation of the basic formulations have changed little since the 1968 edition of AMCA Bulletin No. 2, these are presented somewhat as they appeared in that publication by James B. Gahan but with some notable additions and deletions. At the time the 1968 revision was prepared, the use of concentrate insecticides, granules, flowable solids, microencapsulated and plastic-based formulations had not been or were just being developed. Therefore, these are presented here as new or expanded topics. A glossary of common formulation terms has also been added for the benefit of those persons not familiar with the vocabulary.

CONCENTRATES

In recent years, much of the insecticide used in mosquito control has been applied as ultra low volume aerosols of concentrated insecticides. These concentrates contain a high percentage of active ingredients, usually above 80%; however, because of formulating problems, some insecticide concentrates may contain less than 50% active ingredients.

Concentrate or technical grade insecticides may be solids, liquids or gases and are the commercial form of the basic toxicant. They are not chemically pure since a small percentage of solvent is usually added in order to improve physical properties for handling and storage. Also, technical insecticides may contain chemical isomers or other related chemicals.

Concentrates may be applied without dilution or may be diluted with small amounts of compatible petroleum-based liquids in cases where the use of the undiluted concentrate would not result in the desired discharge volume. Concentrates offer two significant advantages over dilute solutions. No mixing is required, therefore resulting in lower labor and equipment costs. The use of 5–10 gallon spray tanks versus the 100–200 gallon tanks necessary for dilute spraying or thermal fogs allows the use of smaller and lighter vehicles with their inherent savings in operating costs. Another advantage of concentrate spraying is the elimination of the traffic hazard associated with the visability problems of thermal fog applications.

Although ultra low volume sprays of concentrated insecticides are more effective as adulticides than thermal fog applications in higher (8–10 mph) winds, thermal fog applications have been shown to better penetrate densely wooded areas resulting in significantly better mosquito control in these cases. Other disadvantages of concentrate spraying are associated with the physical problems of using liquids of higher viscosity, possible corrosive action of the concentrate, the inherent higher toxicity of the spray solution and the low solubility of some solid insecticides in common solvents. In general, however, the use of concentrated insecticides offers a more economical method for the control of adult mosquitoes by ground equipment and, for this reason, concentrates are widely used today.

SOLUTIONS

Solutions are used to control either adults or larval mosquitoes. They are prepared by dissolving the technical grade insecticides in a liquid solvent. A few technical grade insecticides can be dissolved in water, but most must be dissolved in one of the organic solvents. Crude petroleum oils, which are themselves quite toxic

to mosquito larvae, are frequently used in mosquito control as diluents for insecticides. Since No. 2 fuel oil is readily available, it is frequently used for large scale control operations, but care must be taken in application because of phytotoxicity. Sprays applied inside well-kept houses are generally prepared in deodorized kerosene, which is kerosene that has been refined sufficiently to remove objectionable color and odor.

Some insecticides are not particularly soluble in petroleum products, and auxiliary solvents such as acetone, cyclohexanone, xylene, or heavy aromatic naphtha (HAN) must be used. The choice depends on the solubility of the insecticide and the cost of the solvent. Since solutions of insecticides may be dispersed as thermal aerosols, the flammability of these auxiliary solvents may also be an important factor. Highly volatile materials, however, are desirable in household sprays to avoid oily deposits on furniture and walls. For this use, the insecticide is also often dissolved in the auxiliary solvent first and then diluted with the oil.

Solutions are usually prepared on a weight-per-volume (w/v) basis where a weighed quantity of insecticide is mixed with a measured volume of solvent or on a weight-per-weight (w/w) basis where all ingredients are weighed. Insecticides that are liquids usually dissolve rapidly in oils, but solids dissolve relatively slowly. When solids are prepared as sprays, the mixing is done in large drums or tanks. Some kind of agitation, either rolling or stirring, is used to reduce the time required to form the solution.

Solutions may be applied as sprays, mists or aerosols, depending upon the desired droplet size needed for the control of mosquitoes in a given situation. Medium to coarse sprays are most useful as larvicides; whereas fine sprays, mists, and aerosols are more effective against adult mosquitoes.

Special insecticidal solutions containing liquified gases as propellants are available in small pressurized containers. These prepared aerosol formulations are designed primarily for indoor use.

EMULSIFIABLE CONCENTRATES

If large areas are to be treated, solutions may be expensive, primarily because of the high cost of the kerosene or fuel oil used as the diluent. Also, oils injure tender vegetation if they are used in large volumes or as large droplets. Because of these factors, aqueous sprays of emulsifiable concentrates are often more satisfactory.

Emulsifiable concentrates are formulations which, when mixed with water, form an emulsion. When emulsions are prepared, an emulsifier, or surface-active-agent, is used to stabilize a mixture of one liquid (the dispersed phase) suspended in a larger amount of a second liquid (the continuous phase). Most insecticidal emulsions used today are the oil-in-water type. However, before an oil-in-water emulsion can be prepared, the insecticide must be in liquid form. Insecticides that are solids and those that are viscous liquids must first be dissolved in an organic solvent. The solvents used most commonly are xylene, the petroleum oils, and cyclohexanone. The liquified insecticide is then mixed with an emulsifier to form an emulsifiable concentrate which can be stored until it is needed. Most emulsifiers are organic alcohols, but any substance that lowers the surface tension of water tends to stabilize a water emulsion. When used, the emulsifiable concentrate is added directly to water and forms a milky suspension or emulsion in which the oil is separated into small globules, each of which is coated with a film of the emulsifier and surrounded by water. The emulsifier is effective because most of it is adsorbed at the interface between the two phases and separates them.

Some agitation is required to form an emulsion. In general, the more emulsifier added, the more stable the emulsion. If a sufficient quantity is used, the finished emulsion will remain stable for several hours, and some remain stable for 24 hours or more. When the two phases separate, the one with the lower specific gravity floats to the top; however, properly prepared emulsions can be remixed easily by agitation.

Water is likely to be available at little or no expense anywhere that mosquitoes are a problem. If a choice is available, soft water forms a better emulsion than hard water; however, some emulsions will remain stable even in salt water. In cold climates, the temperature of the water is important because emulsions prepared in very cold water separate more readily than those prepared with warm water. Extremely hot water, however, should never be used because it may have a deleterious effect on the insecticide.

When used as a residual spray, the solvent and the diluent evaporate leaving a deposit of insecticide on the treated surface. In such situation, volatile solvents like xylene are used in emulsifiable concentrates. When emulsions are applied as larvicides, petroleum oils contribute to the effectiveness of the treatment.

Although not frequently used in mosquito control, some emulsifiable concentrates require a gradual addition of water in small quantities. A water-in-oil emulsion is formed first, but as an excess of water is added, the emulsion is inverted to an oil-in-water formulation. These emulsions work satisfactorily but require more

time for preparation than those made by adding the concentrate directly into large quantities of water.

DUSTS

Although insecticidal dusts are highly toxic to mosquitoes, they are more difficult to apply than sprays or granules, and, therefore, they are rarely used today. Dusts were used primarily as larvicides when long-distance drifting was needed to treat large breeding areas, or when a larvicide that remained on the surface for long periods was needed. Also, since dusts penetrated thick vegetation better than liquids, they were sometimes preferred for control of adult mosquitoes in heavily vegetated areas.

When a dust is formulated, the insecticide is mixed with an inert carrier such as clay, talc, silica gel, pyrophyllite, diatomaceous earth, bentonite, hydrated lime, or kaolin. These carriers are classified according to weight or material occupying a definite volume (e.g., lb/cu. ft.). Carriers with low bulk density include silica gel, calcium silicate, and diatomaceous earth. Pyrophyllite, talc, and the clays are classified as high bulk density carriers. Since the physical properties of the carrier can affect the toxicity of a formulation, two classes are frequently used together. Very light materials have a tendency to drift away from the area being treated, but heavy materials become packed or lumpy during storage or while they are being applied.

Sometimes the insecticide and the carrier are blended by stirring the two ingredients together, or grinding them in a ball mill or other blending machine. However, the insecticide is more frequently dissolved in a solvent such as acetone, benzene, or xylene and then sprayed or poured onto the carrier during the grinding process. Either volatile or non-volatile solvents are used, but non-volatile solvents should not be present in an amount that impairs the dusting qualities of the finished product. Since special equipment is required to prepare dusts, commercially prepared products should be used unless the control operations are to be conducted on such a large scale that purchase of the special equipment is justified.

WETTABLE POWDERS

A formulation that has a solid dispersed but not dissolved in water or other diluent is called suspension. It is usually prepared with a water-wettable powder. The wettable powder is an insecticidal dust that is mixed with a wetting agent which allows it to be suspended in water. Like an emulsifier, the wetting agent reduces the surface tension between the solid particles that are being dispersed and the water. The same products are frequently used as emulsifiers and wetting agents.

When a water-wettable powder is formulated, the insecticide and wetting agent are usually dissolved in a solvent such as acetone, xylene, or benzene, and sprayed onto one of the commonly used dust diluents while the powder is agitated to distribute the material uniformly throughout the mixture. Commercial products frequently contain as much as 50–75% of insecticide. The solid particles contained in the powder must be ground extremely fine and be insoluble in water. However, when certain types of kaolin clay are used as the carrier, no wetting agents are needed.

Wettable powders can be suspended in water in two ways. Some wet so easily that they can be poured directly into water, and only slight agitation is needed to form the suspension. Others must be prepared by adding a small amount of water to the wettable powder to form a thick paste before the bulk of the water is added gradually as the formulation is being agitated.

Water wettable powders usually are much safer to handle and apply than emulsions or solutions because the insecticide is less readily absorbed through the skin. Also, since no solvent is present, they often have a less objectionable odor. If not hygroscopic, wettable powders are also easier to store since they can be kept in paper instead of glass or metal containers.

As surface treatments, suspensions are more apt to remain available to adult mosquitoes than emulsions or solutions because they do not soak into the treated surfaces as readily. However, suspensions are sometimes objectionable because they leave a white deposit on surfaces. Another disadvantage of wettable powders is that they may clog small diameter spray nozzles.

GRANULES

Since a significant volume of insecticide applied as a spray or a dust impinges on vegetation and does not reach the water, granular formulations are now used extensively as mosquito larvicides in place of sprays and dusts. Insecticides incorporated into granules give greater penetration of vegetation and as a result their efficacy is greatly increased. Besides improved penetration through vegetation, granules may also be applied at any time of day since they are less affected by thermal air currents and changing winds than sprays or dusts.

Granules, however, have several disadvantages. The percent active ingredient is very low (usually 1% or less by weight) and the shipping cost is quite high. This can sometimes be over-

come by on-site preparation. On some carriers, the active ingredient becomes bound to the carrier and is only partially released in water. Also, the active ingredient in granules sometimes breaks down in storage. This also can be overcome by on-site preparation just prior to use.

Granules are formulated by impregnating or coating coarse material with an insecticide. The carriers used most extensively include celatom, attapulgite, pyrophyllite, and sand and are usually between 16 and 60 mesh in size. The insecticide can be applied to these carriers as an emulsifiable concentrate, as a solution in an organic solvent, or as a powder. The finished preparation should be as dust free as possible, since the fine particles drift considerable distances and may not deposit in the target area. The weight of the granules may also be adjusted to obtain a product that sinks rapidly to the bottom of the breeding area or one that floats on the water surface. Also, granules may be formulated to release the toxicant from the carrier at a particular time or over a period of time. Depending on the manufacturer, these are designated timed release, controlled release, or slow release granules.

MISCELLANEOUS FORMULATION TYPES

Insecticides may be incorporated into many specialty type formulations to be used for a particular type of control. Plastic or resin based formulations are designed to extend the effective period of the toxicant by incorporating it in an inert material such as polyvinylchloride plastic. As the concentration of the toxicant at the surface of the material is reduced, additional toxicant diffuses within the polymer to the surface. Thus, these formulations allow a continuous release of toxicant over a period of from several days to many months. Plaster of Paris and charcoal are also frequently used to prepare slow release briquets of various toxicants.

In addition, insecticides may also be encapsulated in very small amounts (microencapsulation) in order to reduce detoxification of the insecticide or delay its release into the habitat where it will come into contact with or be consumed by the insect. Larger volumes of insecticides are sometimes encapsulated for ease of application in small treatment areas.

Some active ingredients can only be manufactured as solids or semisolids. When these are finely ground or encapsulated and mixed with an oil or other liquid, they are termed flowable solids. Some flowable solids are designed to be used undiluted while others are to be mixed with water and applied similar to emulsifiable concentrates.

Soluble powders, unlike wettable powders, form a true solution when added to water. Initial agitation is usually required to form the solution, but once in solution no further agitation is needed.

Baits are formulations in which the toxicant is mixed with a substance that is attractive to the insect. The high specificity of this type of formulation limits its use to a particular insect or group of insects. They have little or no application in mosquito control.

Fumigants are either gases which become liquid when placed under pressure, or are liquids which vaporize when exposed to air. They are applied by releasing the gaseous stage in a confined area. They also have little application in mosquito control.

There are many other types of special formulations necessitated by formulating problems of certain insecticides or by particular application needs; therefore, the reader is referred to the references at the end of this article and also to insecticide manufacturers and commercial formulators for additional information.

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GLOSSARY OF COMMON FORMULATION TERMS

Absorption—The process by which a chemical is taken into plants, animals, or another substance.

Activator—A chemical added to a pesticide to increase its activity.

Adjuvant—An inert ingredient that is added to a pesticide formulation to enhance its effectiveness.

Adsorption—The process by which a chemical is bound to the surface of a particle or substance.

Aerosol—Any extremely fine solid or liquid particles suspended in air.

Antagonism—A reduction in the toxicity of one insecticide when exposed to or added to another insecticide.

Aqueous—A term indicating the presence of or dilution in water.

Carrier—An inert solid or liquid material used to prepare an insecticide formulation.

Compatible—A term used to indicate that two or more chemicals may be mixed together without adversely affecting their individual properties.

Concentrate—A chemical formulation containing a high percentage of active ingredient.

Concentration—The amount of active ingredient in a given weight or volume of formulation.

Deflocculating Agent—A material which prevents the settling of solid particles in a liquid medium.

Degradation—The process by which an insecticide is broken down chemically into a simpler and usually less toxic form.

Diluent—Any liquid or solid material used to reduce the concentration of the active ingredient.

Dispersing Agent—A material that reduces the attraction between particles.

Dosage—The quantity of active ingredient applied to a given area or unit.

Emulsifier—A chemical which aids in the suspension of one liquid in another.

Hydrogen-Ion Concentration or pH—A measure of acidity or alkalinity (pH 1 to 7—acid, pH 7—neutral, pH of 7 to 14 alkaline).

Immiscible—The property of not being able to be mixed together to form a homogeneous solution.

Incompatible—A term used to indicate that two or more chemicals cannot be mixed together without adversely affecting their individual properties.

Insoluble—The inability of a substance to dissolve in a liquid.

Phytotoxicity—The adverse affect of a chemical on plants.

Safener—A chemical added to a formulation to reduce its phytotoxicity.

Solubility—The ability of a substance to dissolve in a liquid.

Solution—One or more liquids or solids completely dissolved in a liquid.

Solvent—A liquid in which another chemical dissolves to form a solution.

Spreader—A chemical that increases the area that a given volume of liquid will cover.

Sticker—A chemical added to a solution to increase its adherence.

Surfactant—A surface active agent which increases the emulsifying, dispersing, spreading or wetting properties of another chemical.

Suspension—Finely divided solid particles mixed in a liquid in which they are not soluble.

Synergist—A substance which, when combined with another substance, gives an effect that is greater than the sum of their individual effects.

Toxicant—A poisonous chemical.

Toxicity—The adverse affect of a chemical to plants or animals.

Vapor Pressure—The property which causes a chemical to evaporate.

Viscosity—The property of liquids to resist change in form.

Volatility—The rate of evaporation of a liquid or solid.

Wetting Agent—A chemical which increases the liquid contact of a dry material.