



Space spray application of insecticides for vector and public health pest control

A practitioner's guide

*Communicable Disease Control, Prevention and Eradication
WHO Pesticide Evaluation Scheme (WHOPES)*

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Geneva

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1. Introduction

This guide provides information on how to control flying insect pests and vectors of diseases by applying insecticides as space treatments. Space treatments are usually designed to provide a rapid knock-down and mortality with little or no residual effect. Such treatments must be considered in conjunction with other control methods as part of an integrated vector management programme. Space spraying provides a rapid method of control in emergency or epidemic situations and may be used for seasonal control of flying insect pests or vectors. However, it may not be ideal for all vectors or situations and as such may not be an economical method of control.

The aim of space treatments is to rapidly reduce populations of flying insect pests and vectors. An additional objective may be to reduce or interrupt the transmission cycle of insect-borne diseases. Among the disease vectors affecting public health, the most important and widespread are mosquitoes, houseflies, sandflies and other biting flies; some of these may be targeted for space treatment.

Immediate killing of actively flying insects requires a cloud of insecticide droplets that they will encounter in flight. To be cost-effective and obtain good biological efficacy, space spraying requires:

- knowledge of the behaviour and biology of the target species – to understand where and when space treatments will be effective;
- knowledge of insecticides and formulations most suitable for space spraying;
- knowledge of pesticide application technology – to know which equipment is needed and how to use it; and
- monitoring and surveillance of the target species and vector-borne disease problem to evaluate the efficacy of the programme.

2. Space spray treatments

A space spray – technically a fog (sometimes referred to as an aerosol) – is a liquid insecticide dispersed into the air in the form of hundreds of millions of tiny droplets less than 50 µm in diameter. It is only effective while the droplets remain airborne. Space sprays are applied mainly as thermal fogs or cold fogs.

2.1 Thermal fog

The insecticide used in thermal fogs is diluted in a carrier liquid, which is usually oil-based. Hot gas is used to heat the pesticide spray, decreasing the viscosity of the oil carrier, and vaporizing it. When it leaves the nozzle the vapour hits colder air and condenses to form a dense white cloud of fog. Most of the droplets are smaller than 20 µm. The droplet size is affected by the interaction between the formulation, the flow rate and the temperature at the nozzle (usually > 500 °C). The volume of spray mixture applied in vector control is usually 5–10 litres per hectare, with an absolute maximum of 50 litres per hectare. The hot emission gas is obtained from engine exhaust, friction plate/engine exhaust or from a pulse jet engine.

Advantages

- Easily visible fog so dispersal and penetration can be readily observed and monitored;
- Good public relations in some circumstances as people can see something being done about the problem; and
- Low concentration of active ingredient in the spray mixture and reduced operator exposure.

Disadvantages

- Large volumes of organic solvents are used as diluents, which may have bad odour and result in staining;
- High cost of diluent and spray application;
- Householders may object and obstruct penetration of fog into houses by closing windows and doors;
- Fire risk from machinery operating at very high temperatures with flammable solvents; and
- Can cause traffic hazards in urban areas.

2.2 Cold fog

With cold fogs the droplets are formed by the mechanical breaking up of the spray mixture, either by passing it through high-pressure nozzles or by passing a slow stream of the mixture through a high-velocity vortex of air. Some equipment is fitted with high-speed rotary nozzle(s). The spray droplets are generated without any external heat. With cold fogs the volume of spray is kept to a minimum. Ultra-low-volume insecticide formulations are commonly used for such applications.

Advantages

- The amount of diluent is kept to a minimum, resulting in lower application cost and increased acceptability. Some formulations are ready to use, thereby reducing operator exposure;
- May use water-based and water-diluted formulations, which pose a low fire hazard and are more environmentally friendly;
- Because a lower volume of liquid is applied, application is more efficient; and
- No traffic hazard as the spray cloud is nearly invisible.

Disadvantages

- Dispersal of the spray cloud is difficult to observe; and
- Higher technical skills and regular calibration are required for efficient operation of equipment.

3. Space spray equipment

Selection of appropriate equipment for space spraying depends on the size and accessibility of the target area as well as the human resources and operational capacity of the programme. Sometimes smaller machines may be needed in conjunction with vehicle-mounted equipment to treat narrow pathways and other areas inaccessible to vehicles or sheltered from prevailing air movements, e.g. the lee side of buildings and inside dwellings.

Cold fog equipment is recommended where thermal fogs may cause a traffic hazard. Aerial application of space sprays may be justified where access with ground equipment is difficult and/or extensive areas need to be treated very quickly. This, however, requires aerial spraying expertise, which is unavailable in most control programmes so that the task usually has to be contracted out.

The selection of equipment should ideally be based on familiarity, suitability and performance. Advances in equipment design should be considered when purchasing equipment.

A brief description of the main types of space spray equipment is provided below. More detailed information, as well as WHO specifications for quality control of pesticide application equipment, is available in the WHO manual, *Equipment for Vector Control*¹.

3.1 Equipment for thermal fogging

3.1.1 Hand-carried thermal foggers

These are used for treating houses and certain outdoor areas of limited size or accessibility, e.g. markets, hotel grounds and parks (Figure 1). There are two types of hand-carried thermal foggers, pulse jet and friction plate.

¹ *Equipment for vector control*. Geneva, World Health Organization, 1990.

Pulse jet

These machines are fitted with a pump (piston, bellows or electric) and a set of batteries linked to a spark plug. To start the engine, the pump is operated and the switch used to connect the battery power to the spark plug. When petrol is ignited in the combustion chamber by the spark plug, the batteries are no longer used as the hot exhaust gas ignites subsequent charges of fuel and air. A pulse jet engine will continue to operate as long as fuel is supplied through the carburettor. The hot exhaust moves down a long tube to the nozzle, where the insecticide is injected into the hot gas. The machine operates with a very loud pulsating noise. A simple fixed restrictor controls the flow rate on most machines. Flow rates up to 25 litres per hour may be achieved. Machines should be fitted with a safety valve to stop the flow of insecticide to the nozzle when the engine ceases to operate.

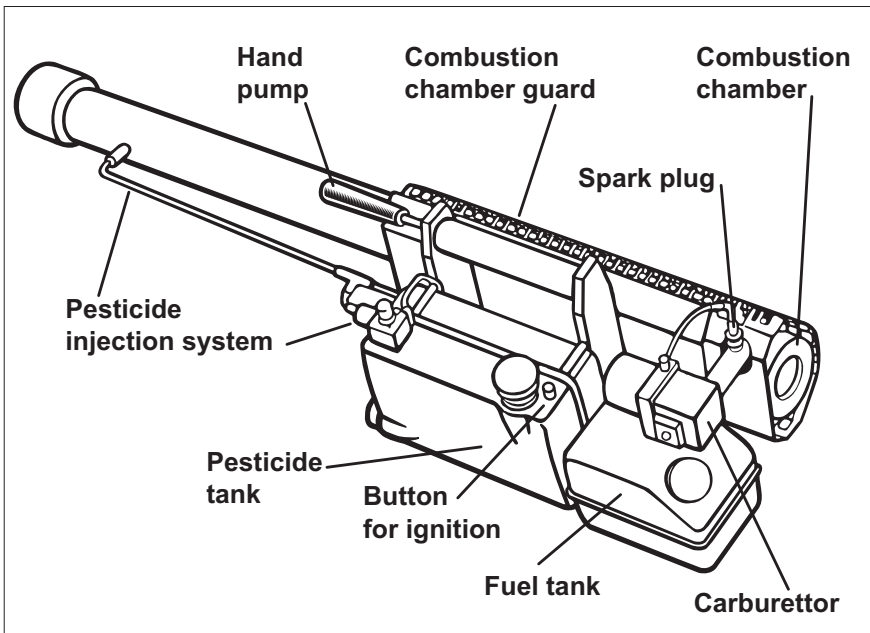


Figure 1. *A hand-carried thermal fogger*

Friction plate

This type of machine consists of a 1–3 hp 2-cycle engine driving a “friction plate” inside the insecticide tank, which preheats the insecticide and fuel oil mixture. This plate also serves as part of the pump that delivers

the liquid to the engine exhaust. The hot exhaust gases generate and disperse the fog. Friction plate devices operate at a lower temperature than pulse jet engines.

3.1.2 Vehicle-mounted thermal foggers

Large thermal fog generators use an air-cooled motor to run an air blower, fuel pump and insecticide pump. Air from the “roots type air blower” is delivered into the combustion chamber. There it is mixed with gasoline vapour and ignited, so that temperatures reach 426–648 °C. The diluted insecticide liquid is pumped via a simple flow delivery valve and injected into a cup in the fog head or directly into the nozzle. The insecticide liquid is vaporized by the blast of hot gases. Despite this high temperature, trials with some insecticides recovered at the jet tip show very little degradation of active ingredient. This is because the time spent at that temperature is only a fraction of a second, which is not long enough to cause serious degradation. The hot gases then pass out of the machine. As the hot oil vapour is discharged through a relatively large nozzle into the cooler outside air, it condenses to form very small droplets of thick white fog. Delivery rates of up to 10 litres per minute can be achieved with larger machines.

3.1.3 Aircraft application of thermal fogs

For aircraft application of thermal fogs the diluted insecticide formulation is fed into the aircraft exhaust. The exhaust is adapted with vanes to swirl the fog droplets as they are formed. The application of thermal fogs by aircraft has been very limited.

3.2 Equipment for cold fog application

3.2.1 Hand-carried cold foggers

Most of these machines have a 1–3 hp, 2-cycle gasoline engine which drives a blower unit to discharge air through the nozzle. Air may also slightly pressurize the insecticide formulation tank so that the liquid is fed via a restrictor to the nozzle. However, negative pressure generated by the air flow passing through the nozzle allows liquid to flow from the tank.

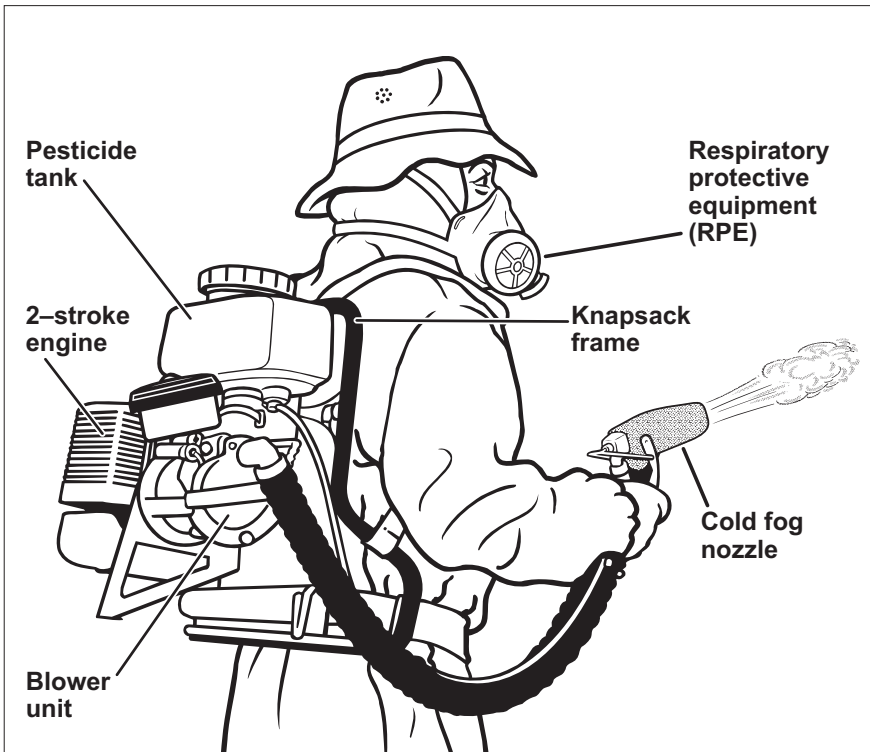


Figure 2. *A knapsack cold fogger*

These machines are small and weigh 6–11 kg. In addition to hand-carried units, knapsack cold fogging units are also available (Figure 2), as are several electrically driven models.

Flow rates range from 1 to 4 litres per hour. A metering valve or preferably a fixed or changeable orifice controls the flow rate. These machines are ideal for indoor space treatments and for small areas outdoors where vehicle access is limited.

3.2.2 Vehicle-mounted cold foggers

A 5–20 hp 4-stroke gasoline engine is used to drive a high volume air blower, forcing air at a rate of approximately 6 m³ per minute at low pressure (50 kPa) to one or more nozzles (Figure 3). The angle of projection of the cold fog from these nozzles can be adjusted. The pesticide container may be pressurized to force the formulation to the nozzle, or positive-displacement pumps may be used.

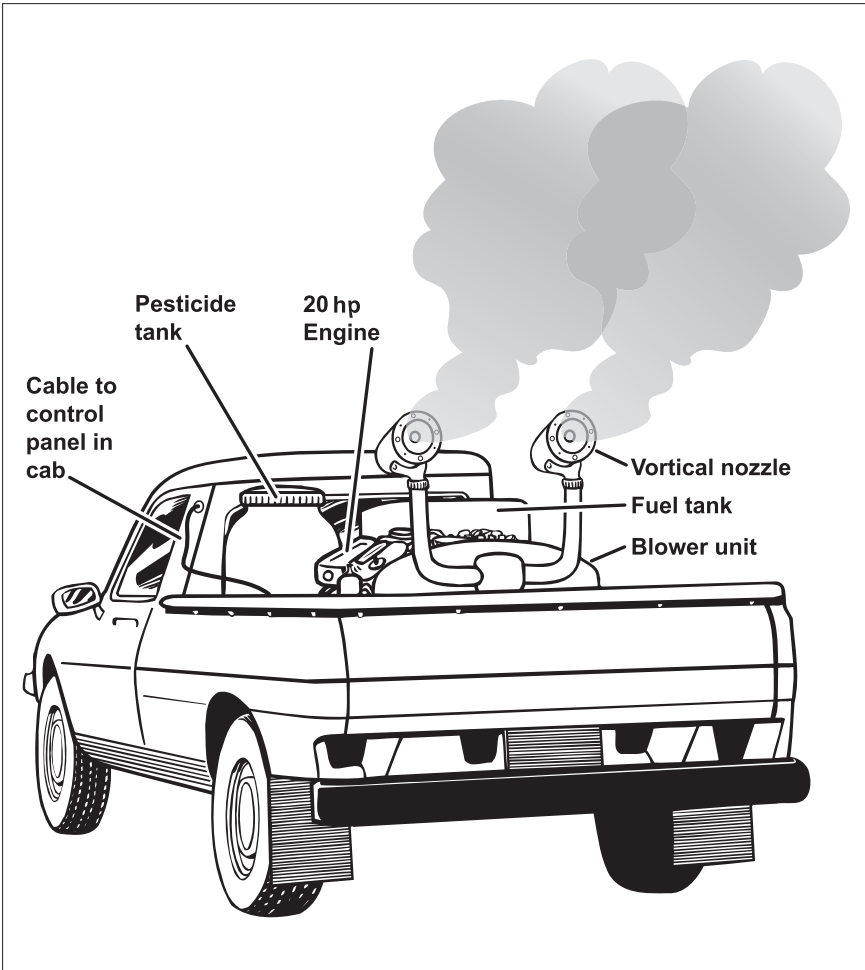


Figure 3. *A vehicle-mounted cold fogger*

Where positive-displacement pumps are used, they can be linked electrically to the vehicle in order to vary output as a function of vehicle speed. In particular, spraying ceases when the vehicle stops.

Alternatively a high-pressure, low-volume air source is used with an air compressor, rather than a blower. On these machines, nozzles ranging from the standard industry “paint gun nozzle” to proprietary nozzles that atomize well up to a flow rate of 0.5 litre per minute are available. Another design uses a rotary nozzle coupled with an electric motor which operates at a very high speed.

3.2.3 Aircraft application of cold fogs

Both fixed-wing aircraft and helicopters have been used to apply cold fogs. Conventional low-volume nozzles (e.g. flat fan) have been used on fixed-wing aircraft to create fine sprays, using moderate or high pressures. However, the droplet spectrum is generally poor so preference is given to the use of rotary atomizers or very-high-pressure systems.

A rotary atomizer (Figure 4) has a cylindrical metal gauze rotated at high speed by an electric motor or by fan blades rotated by the forward speed of the aircraft. The pitch of the blades is adjustable so that the rotational speed of the atomizer can be set in relation to the aircraft speed. In addition to the centrifugal force producing droplets, air shear breaks the liquid into smaller droplets.

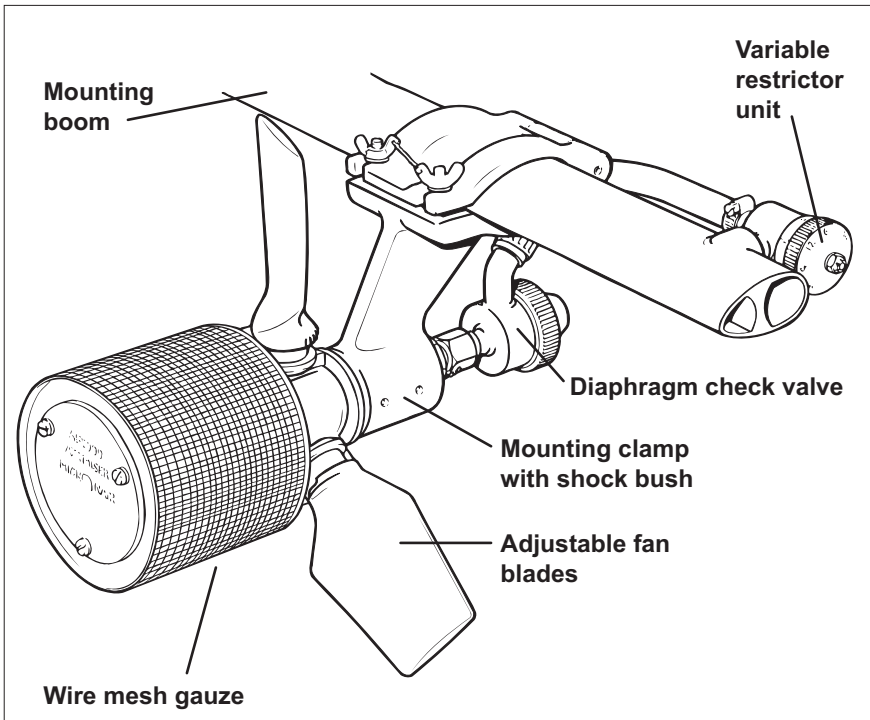


Figure 4. A rotary atomizer for aircraft application of cold fogs

4. Insecticide products for space spraying

Space-spraying formulations have traditionally been oil-based. The oil carrier inhibits evaporation of small fog droplets. Only insecticide products with highflash points should be used for thermal fogging.

Diesel is used as a carrier for thermal fogging, but creates a thick smoke and oily deposits, which may lead to public rejection. For environmental reasons, water-based formulations have been made available in recent years. These formulations may also contain substances that prevent rapid evaporation. Table 1 lists selected insecticides suitable for space spraying against mosquitoes. These insecticides may also be used against other insect pests and vectors, but different dosages may be required.

Table 1. Selected insecticides suitable for cold or thermal fogging for mosquito control

<i>Compounds</i>	<i>Dosage of active ingredient (g/ha)</i>
Organophosphates	
fenitrothion	250–300
malathion	112–600
pirimiphos-methyl	250
Pyrethroids	
cyfluthrin	1–6
deltamethrin	0.5–1.0
lambda-cyhalothrin	1.0
permethrin	5–10
resmethrin	2–4

Formulations for space spraying are:

Hot fogging concentrate (HN). A formulation suitable for application by thermal fogging equipment, either directly or after dilution.

Ultra-low-volume liquid (UL). A homogenous liquid ready for use through ULV equipment which is specially formulated for low volatility.

Emulsion, oil in water (EW). A heterogenous fluid formulation consisting of a solution of insecticide in an organic liquid dispersed as fine globules in a continuous water phase.

Emulsifiable concentrate (EC). A homogenous liquid formulation to be applied as an emulsion after dilution in water or oil.

Formulations such as wettable powders (WP), suspension concentrates (SC) and water-dispersible granules (WG) are unsuitable for space spraying. An appropriate formulation must be chosen and the label instructions carefully followed for all applications. WHO specifications for pesticides, for quality control and international trade, are available at: www.who.int/ctd/whopes.

5. Space spray treatments – general considerations

5.1 Optimum droplet size

Space treatments are only effective while the droplets remain airborne. Droplets will fall by gravity and some are deposited on horizontal surfaces while the majority will be lost to the atmosphere especially in outdoor spraying.

The speed at which droplets fall is determined by the mass of the droplet, e.g. a droplet of 20 μm diameter will fall at 0.012 minute per second, taking 14 minutes to fall 10 metres in still air, whereas a 100 μm droplet falls at 0.279 minute per second and will take only 36 seconds to fall the same distance (Table 2).

Droplets bigger than 30 μm in diameter are less effective as they do not remain airborne for sufficient time. Droplets smaller than 5 μm in diameter do not readily come in contact with flying insects, as the movement of the smallest droplets is affected by the air turbulence created by the insect's flight. It is generally accepted that droplets should be generated at 10–30 μm so that, even with some evaporation and after some time, they remain in the correct range for optimal airborne suspension and insect impact.

Table 2. *Density and fall of fog droplets when applied at the rate of 1 litre per hectare (a theoretical model)*

<i>Droplet size (μm)</i>	<i>Time to fall 10 m</i>	<i>Droplet density (no./cm^3)</i>
1	93.7 hours	19120.0
5	3.7 hours	152.0
10	56 minutes	19.2
20	14 minutes	2.38
50	135 seconds	0.150
100	36 seconds	0.0192

In dry climates, especially if the pesticide is diluted in a volatile carrier (e.g. water), the evaporation of the diluent will cause the droplets to shrink; slightly larger droplets are thus desirable.

For a given volume of spray mixture, the smaller the droplet size the greater the number of droplets. If 1 ml of spray mixture is dispersed as 20 μm droplets (each containing 4.2 picolitres), there will be 239 million droplets produced, whereas if the same volume is dispersed as 100 μm droplets (534 picolitres) there will be 1.91 million droplets. The large number of droplets greatly increases the chances of contact being made with a flying insect as the density per unit volume of air will be so much greater (see Table 2).

The optimum droplet size for space spraying against mosquitoes is 10–20 μm , for larger flies, e.g. tsetse flies, the optimum is 30 μm .

5.2 Droplet size parameters

Several parameters (Figure 5) are used to characterize the size of droplets, which in turn is influenced by the nozzle design and operating criteria, especially the flow rate.

Volume median diameter (VMD)

The volume median diameter (VMD), expressed in μm , is the number that divides the spray into two equal parts by volume, one half containing droplets smaller than this diameter, the other half containing larger droplets. A few large droplets can significantly change the VMD. The value of the VMD does not indicate the range of droplet sizes.

Number median diameter (NMD)

The number median diameter (NMD) is the value that divides the spray into two equal parts by number of droplets, so that half the droplets are smaller and half larger. The NMD is more difficult to measure and results may vary for different sampling measurement techniques.

Span

Span is determined from the diameter of the 90 percent value (V_{90}) by volume minus the 10 percent value by volume (V_{10}), divided by the VMD. The formula is:

$$\text{Span} = \frac{V_{90} - V_{10}}{\text{VMD}}$$

The value of span gives an indication of the range of droplet sizes and is ideally less than 2.

While the VMD, NMD and span indicate the quality of a fog, the critical factor is the maximization of the number of droplets in the optimal size range.

5.3 Flow rate

Most equipment used to apply space sprays will produce a range of droplet sizes. The VMD generally increases as flow rate increases. However, with some machines an increase in flow rate can be compensated by increasing the air pressure. It is therefore essential to check the droplet spectrum at different flow rates. Table 2 illustrates the need to ensure the correct droplet spectrum as too few droplets will remain airborne if they are too large. If

the droplet size is doubled, the number of droplets is reduced eightfold. This could seriously reduce efficacy because there will be too few droplets in the air for insufficient time. To maintain efficiency, a compromise is thus needed between droplet size and droplet numbers (governed by flow rate).

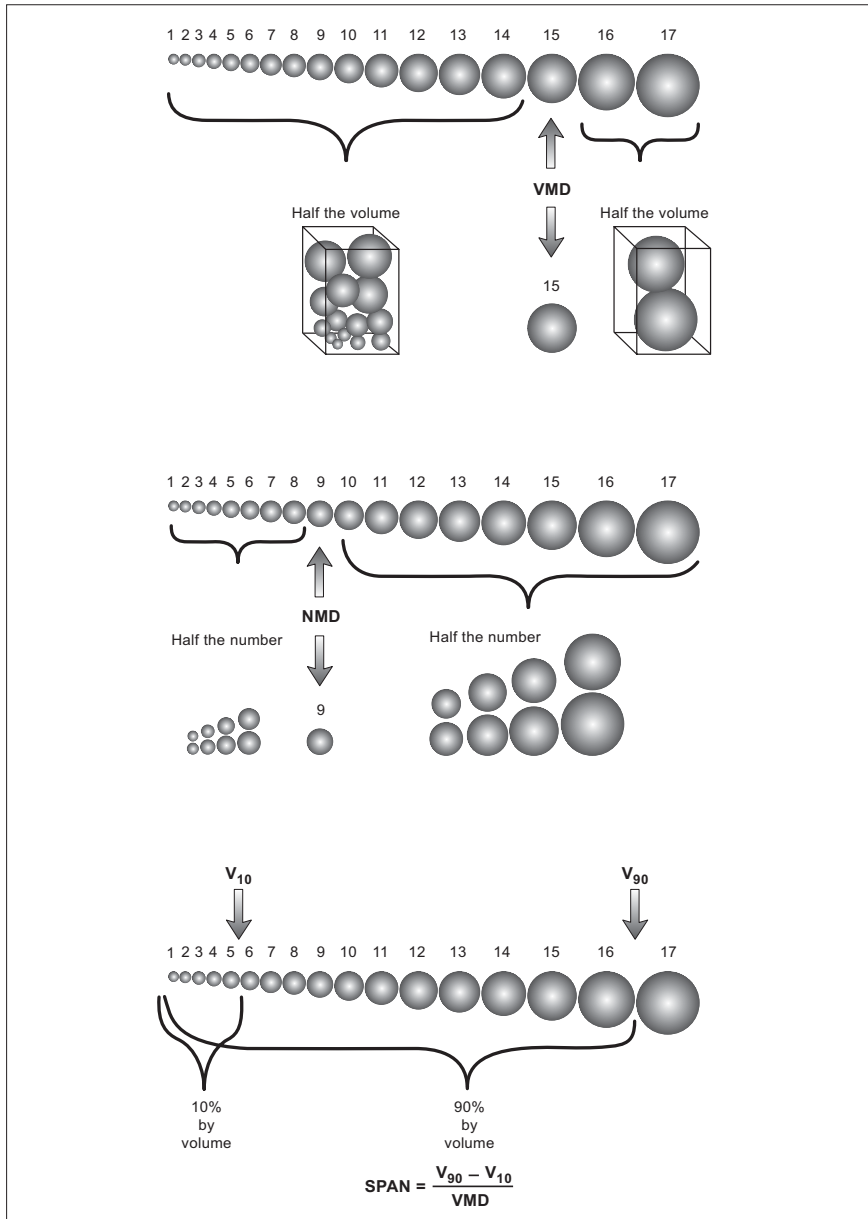


Figure 5. Droplet size parameters; volume mean diameter (VMD), number median diameter (NMD) and span (the diagram of VMD and NMD was originally by Hans Dobson, University of Greenwich)

5.4 Spray concentration

The manufacturer's recommendations for the targeted amount of active ingredient per unit area must remain within the specified range. However, the spray concentration and the rate of application can be adjusted. Any dilution of the formulation must be compensated by an increase in the volume of spray per unit area (this can be achieved by increasing the flow rate of the machine, slowing the ground or air speed at which the machine travels, or reducing the swathe width).

For a flying insect to be killed, it must acquire a lethal dose of insecticide in the droplets that impact on it. The lower the concentration of active ingredient, the larger the number of droplets of a given size required to achieve a lethal dose.

Ultra-low-volume spraying aims, largely for operational reasons, to minimize the total volume of diluted insecticide applied (usually < 2 litres per hectare).

5.5 Wind speed

Wind speed has a profound effect on droplet distribution and impingement on insects. In most situations a wind speed of 1–4 metres per second (approximately 3.6–15 km/hour) is needed to drift the droplets downwind from the line of travel. Spraying should not take place when wind speed exceeds 15 km/hour. Wind speed can be measured using a hand-held anemometer.

The type of terrain and vegetation affects air movement and hence the distribution of the droplets. In open terrain with relatively sparse vegetation, wider effective swathes can be obtained than in urban areas where the obstruction of buildings alters the flow of air. Penetration of droplets into houses depends on the design of the house and whether windows, doors and eaves are open. In urban environments the road layout determines the route; however, this may not correspond to the effective swathe width. An increase in the volume application rate may be needed to compensate for reduced droplet penetration into areas of vegetation. For practical purposes most manufacturers consider a 50-metre swathe as the basis for calculating recommended application rates.

5.6 Wind direction

With vehicle-mounted and aerial spraying the spray route must take account of the wind direction to maximize the distribution of the spray throughout the target area. Figure 6 illustrates the spray application route relative to wind direction.

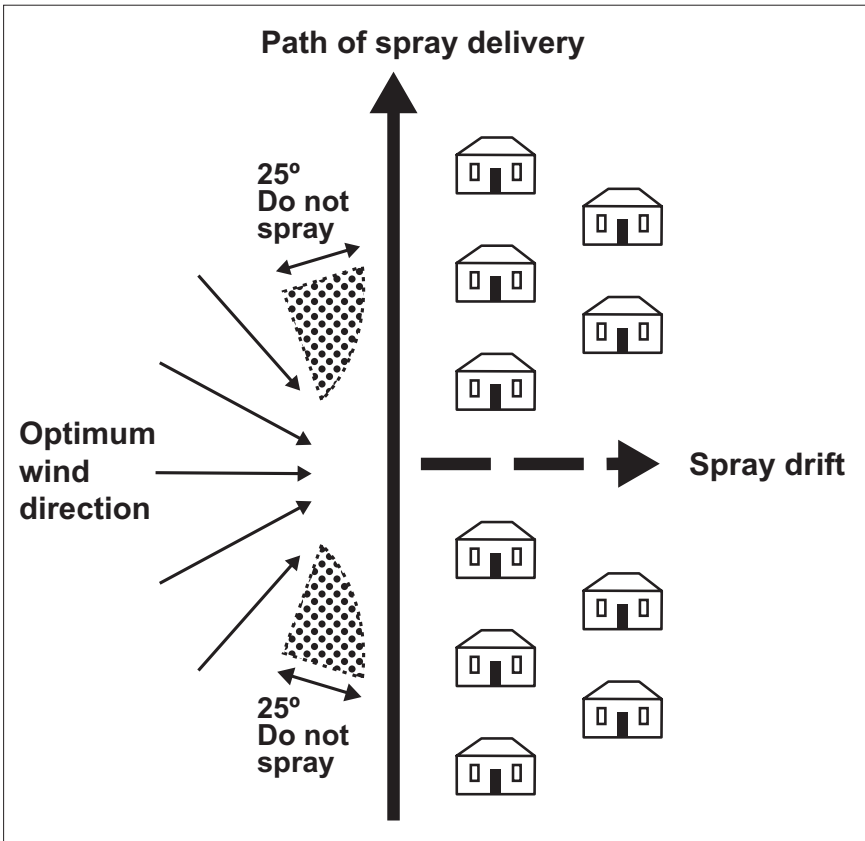


Figure 6. *Spray application route relative to wind direction*

5.7 Temperature effects

In direct sunlight the ground is heated. This causes air to rise. In the middle of the day outdoor space spraying will largely be wasted as the spray droplets will tend to rise upwards rather than drift horizontally. Ideally an inversion is needed, i.e. colder air closer to the ground. This generally

occurs early in the morning after the ground temperature has fallen during the night, but can also occur in the evening when the sun has set and ground temperatures begin to fall. Under an inversion spray droplets will drift close to the ground. Air characteristics, ideal for ground and aerial space spraying, can be observed from smoke rising from chimneys or fires, or can be checked using smoke generators (Figure 7).

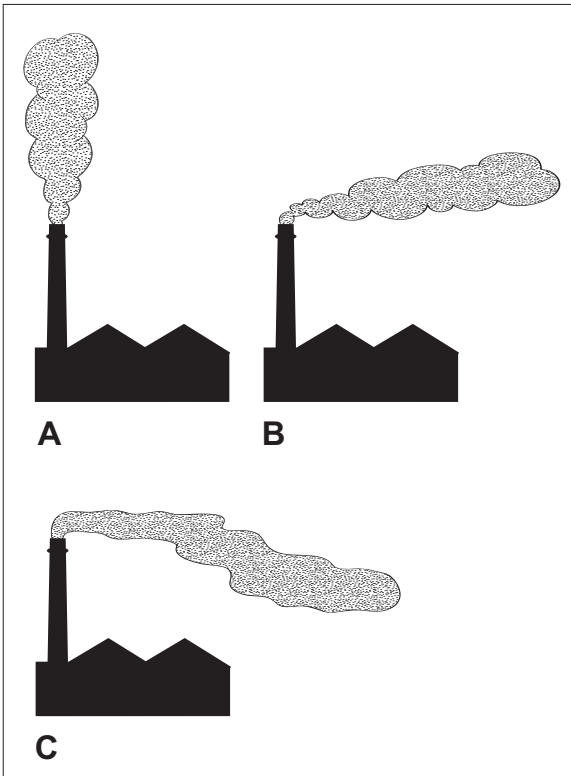


Figure 7.
Air movement as indicated by smoking chimneys: (A) still; (B) in wind; (C) under inversion.

5.8 Time of treatment

Local knowledge of the time(s) of peak flight activity of the target species is crucial to ensure that space treatments are planned to coincide, as far as possible, with these times (Figure 8). Fortunately, peak flight activity of many vectors is around dusk and/or dawn, when weather conditions are often favourable for space treatment. However, some insects, notably houseflies and similar species, are more active during the day and before sunset. *Aedes aegypti* and *Aedes albopictus*, mosquito vectors of dengue fever, are active during daytime, with peak flight activity in the morning

and afternoon. With these species a compromise is usually made outdoors by spraying in the early morning or late afternoon. The timing is less important if indoor spraying is conducted. When other flies are active in the day-time, and conditions are not ideal for spraying because of high temperatures, treatments are usually conducted in the morning before temperatures get too high.

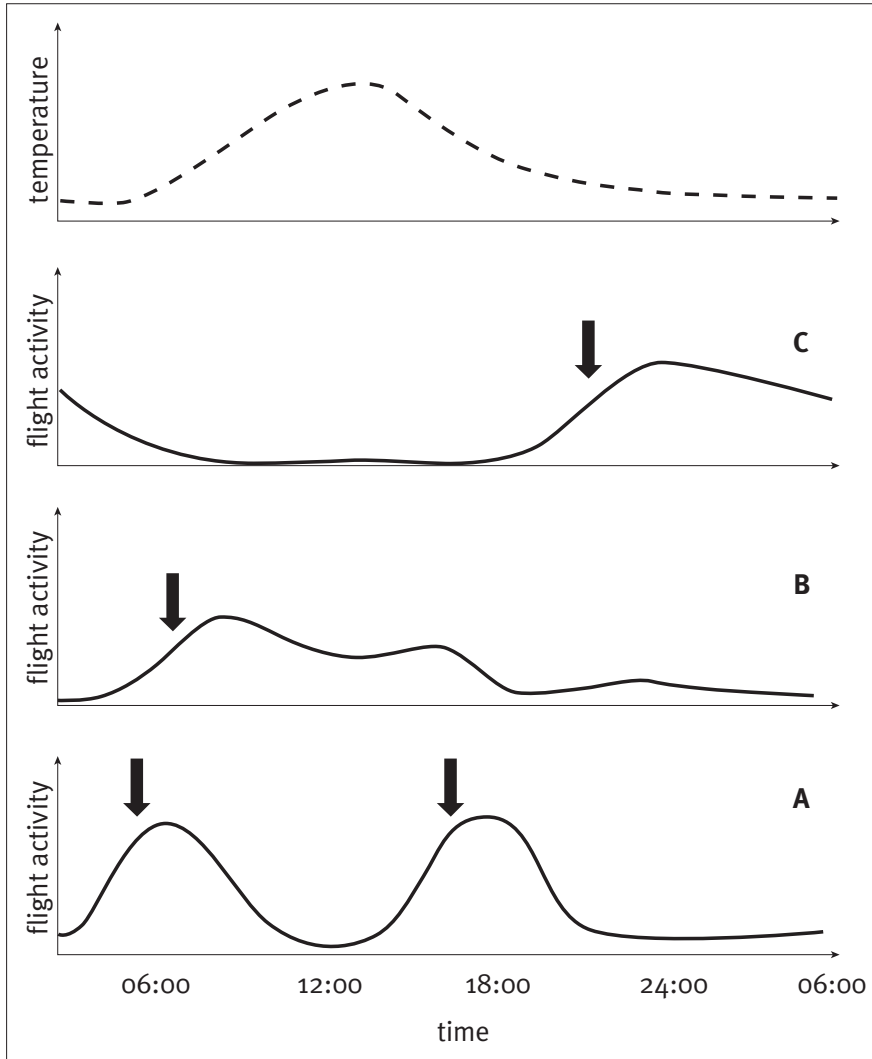


Figure 8. Illustrative examples of optimal space spray application time relative to flight activity of target species (A, crepuscular; B, diurnal; C, nocturnal) and temperature

6. Operational guidelines

6.1 Pre-spray activities

Before embarking on any space spray treatment it is essential to clearly define the problem, the pest species involved and its behaviour, and to characterize the area for treatment. This will allow for appropriate planning and will ensure that all the equipment and resources required are available for timely and efficient operations.

6.1.1 Planning and needs assessment

When planning a space spray operation it is necessary to identify the location and magnitude of the pest or vector-borne disease problem and the epidemiological situation. The pest species or vector and its breeding sites must also be identified. The latter will assist in defining the geographical area to be targeted for spray operations. The flight behaviour and peak flight activity times of the target species must be ascertained to optimize the effectiveness of the operation through proper timing of the spraying.

The area for space treatment must be well defined and characterized, including the density of the human population, type of dwellings/buildings, road layout, vegetation and accessibility. These factors will assist in determining the most appropriate space spray application method(s) and choice of equipment. Vehicle-mounted equipment is suitable only if there is a good network of roads. Portable equipment is more versatile and can complement vehicle-mounted equipment for spraying areas that are otherwise inaccessible and for treating the insides of buildings, but coverage is slower. Aerial treatments are usually limited to extensive areas requiring rapid coverage or to large areas with poor ground access.

Maps are needed to facilitate advance planning of spray routes. If suitable maps of the area are unavailable it may be necessary to prepare them. The total area in hectares should be calculated and then the options

for spray routes must be established. The route distances and vehicle or walking speeds should be calculated so that the correct dosage can be applied for the flow rate of the machine.

When choosing an insecticide product, consideration must be given to the susceptibility of the vector to the insecticide compound and to the suitability of the product for the application equipment. WHO standard test kits and procedures for determining susceptibility (details are available from WHO Communicable Disease Control, Prevention and Eradication, 1211 Geneva 27, Switzerland) should be used and the implications of the results on the efficacy of the spray operations should be determined. It is noteworthy that there are insecticide products for space spraying which contain synergists to offset the effects of certain insecticide resistance mechanisms.

Selected insecticides for space spraying are listed in Table 1. Final application costs per hectare for the recommended dosage should also be calculated and compared when making the decision on which insecticide to purchase. This calculation will include the cost of handling and transportation as well as that of any diluent/carrier which may be needed. WHO specifications for pesticides (<http://www.who.int/ctd/whopes>) should be used for quality control.

In choosing application equipment and insecticide products for space spraying, after-sales services of the manufacturer should be taken into consideration. These include training and disposal of insecticide containers. The value of these additional services is increasingly important in relation to the overall costs of the spray programme.

In order to decide on the number of treatments and the interval between treatments, the purpose of the operation must be well-defined, i.e. abatement of nuisance species or interruption of transmission of a vector-borne disease. For the latter, the interval will be less than the incubation period of the pathogen in the vector.

The number and type of machines (e.g. portable or vehicle-mounted), and the number of machine operators and ancillary personnel will be determined by the size and characteristics of the area to be treated, the time needed to complete each application cycle and its frequency. Consider the following example: 1000 hectares per day must be sprayed by vehicle-mounted equipment. Operations are limited by weather condi-

tions and flight activity of the target species to 2–3 hours in the evening. Assuming that one machine can cover 60 hectares per hour (180 hectares in 3 hours of operation), six machines will be needed to complete this task in one evening. Alternatively, three machines can treat the area in two evenings.

Two persons are normally needed for each vehicle-mounted fogger, one to drive and the other to be responsible for the equipment. Operators must be well trained in the safe use and maintenance of the equipment as well as in the safe handling and application of insecticides. Operations must be adequately supervised. A sufficient number of trained personnel, including supervisory staff, must be available to provide coverage in the event of absences due to sickness or other unforeseen circumstances.

All personnel involved in space treatments must be provided with protective equipment including overalls and respiratory and ear protection equipment.

The public should be well informed in advance about the purpose and schedule of operations and how they can cooperate. To allay public concerns, information should also be provided about the safety of the treatments and may include specific advice, for example, to beekeepers and pet owners. A “hotline” may be established so that members of the public can obtain further information. In urban areas, the police and fire departments should be informed of the schedule of operations.

6.1.2 Calibration of the equipment

Each insecticide has particular physical and chemical properties and biological effectiveness. Insecticide manufacturers recommend different dosage rates for specific control situations and target species. Each machine must therefore be calibrated to ensure that the correct amount of insecticide is delivered.

The output rate of the machine (delivered volume per unit of time) will depend on the speed of the vehicle (or walking speed or time per house/room with portable equipment), effective swathe width (metres) and quantity of the chemical preparation as per manufacturer’s recommendation (litres per hectare, including any carrier substances).

Outdoor applications

To calculate the output rate of *vehicle-mounted equipment*, the vehicle speed and width of the track spacing² are needed. Thus a 50-metre track spacing and a vehicle speed of 12 km/hour, 50 x 12 000 m/hour, will permit the treatment of 600 000 m² per hour, equivalent to 10 000 m² (1 hectare) per minute. In this example, if the insecticide label recommends an application rate of 0.5 litre of UL formulation per hectare, the flow rate must be adjusted to deliver 0.5 litre per minute.

Most ULV machines can be easily adjusted to achieve the required flow rate but thermal foggers may require a change of restrictor.

When using *portable equipment*, at a walking speed of 60 metres per minute and with track spacing of 10 metres, 600 m² can be sprayed in one minute (0.06 hectares per minute). For an application rate of 0.5 litre per hectare, the flow rate must therefore be 30 ml/minute (500 ml x 0.06).

Indoor applications

Equipment calibration for indoor applications is usually based on dosage per house or room. Thus it is necessary to calculate the time required to spray a house or room. With a flow rate of 20 ml/minute, and the area of a house being 0.04 hectare (400 m²), the target application rate of 0.5 litre per hectare (500 x 0.04) is delivered in one minute. *Similar calculations are needed when treating other situations, such as refuse areas for fly control.*

Measurement of the flow rate

The method of measuring the flow rate of space spraying equipment depends to some extent on the design of the machine. Where there is a variable flow control, it is set at a mid-point initially. Otherwise the restrictor is fitted according to the manufacturer's instructions. A stopwatch and a graduated cylinder are needed, but first the machine should be operated so that the engine speed provides the correct insecticide tank pressure. The spray is discharged for sufficient time to fill the tubes between the tank and the nozzle. If possible, the discharge tube is disconnected from the atomizer head, and held at the same level. The spray is switched on and the spray mixture is allowed to flow for one minute.

² *As the movement of a vehicle is defined by the layout of roads, it is usual to determine the track spacing rather than the actual swathe width.*

The liquid is collected in the graduated cylinder or in a jug and then transferred to the graduated cylinder. The flow rate is measured in millilitres per minute.

The flow rate of viscous formulations, e.g. technical malathion, will change significantly with changes in temperature. The flow rate must be readjusted for any change in temperature of 5 °C degrees or more. If a machine is calibrated at a stated insecticide temperature, the machine should be used for operations under the same or nearly identical conditions, or the flow rate may differ greatly from that previously calibrated. For conditions where temperatures vary widely, e.g. from 20 °C to 35 °C, a graph should be plotted of the flow rate at different temperatures. Since they may not be accurate, it is unwise to rely totally on flow meters or panels supplied with the machine.

Calibration of a machine should be done periodically, usually after 25 hours of operation, or at any time when major maintenance is performed. Similarly, if a change of insecticides is made, recalibration is needed. For any change of insecticide or major operating conditions, a sample of droplets should be measured to verify acceptable droplet size.

When it is not possible to use the calibration technique described above, or to collect the liquid emitted at the nozzle, an alternative technique is to time the discharge of a known volume. There are two ways to do this. The first is to mark a level on the tank, then to spray for one minute and measure the volume of liquid needed to fill the tank back to the mark. The other is to add a measured volume of the insecticide spray to the empty tank and time how long it takes to spray the liquid.

6.1.3 Droplet sizing

The collection of droplets on slides and their subsequent microscopic examination has been widely used to assess the quality of space treatments (see below). However, alternative rapid and more accurate techniques, including laser-based methods and hot wire anemometry, are now available.

Laser-based techniques

Several devices use a laser light source for measuring the droplet spectra produced by different nozzles. These include light diffraction techniques to measure droplets sampled within a section of the laser beam (spatial sampling). Alternatively the size of droplets passing the intersection of

two laser beams may be used (temporal sampling). In other devices, a digital image of the droplets is captured and analysed to measure the spray spectrum. Manufacturers can provide detailed information on the performance of their equipment with different flow rates and spray liquids. As they are expensive and essentially laboratory-based instruments, they are not used to check whether equipment is maintaining its specified performance in the field.

Hot-wire anemometry

This is an electronic method that is both fast and convenient (Figure 9). With this type of device droplets are measured by impingement via a very fine heated wire on a probe inserted into the stream of fog. As the sample surface is extremely small, it is principally suitable for use relatively close to an aerosol nozzle, emitting a very large number of droplets, travelling at 5–10 m/s. The instrument is linked to a laptop computer and is portable and can therefore be used to check the droplet spectrum produced by cold foggers. Between readings the probe must be washed carefully with a solvent, e.g. acetone. *Hot-wire anemometry is not suitable for use with thermal foggers.* Droplet sizing is normally required after every 50–100 hours of machine operation or after a long period without use. The sprayer should be operated for a period before sampling so that any solid particles in the system are blown away before they can damage the hot wire sampler.

Slide wave technique

If modern equipment is not available, simple assessments can be made with the slide wave technique, using coated glass microscope slides. There are three coatings, magnesium oxide, silicone or Teflon®. Magnesium oxide is suitable for all formulations including water-based sprays. The other coatings have been extensively used for non-volatile/oil-based insecticide formulations. The craters in magnesium oxide or non-volatile droplets on coated slides are then examined under a microscope and the parameters – VMD and NMD – are calculated, taking into account any spread factors.

Magnesium oxide-coated slides are prepared by burning two strips of magnesium ribbon, each 10 cm in length, below a glass slide to ensure that the central area is coated uniformly. This is done with the slide in contact with a metal stand to prevent unequal heating and cracking of the glass. On impact with the magnesium oxide an insecticide droplet

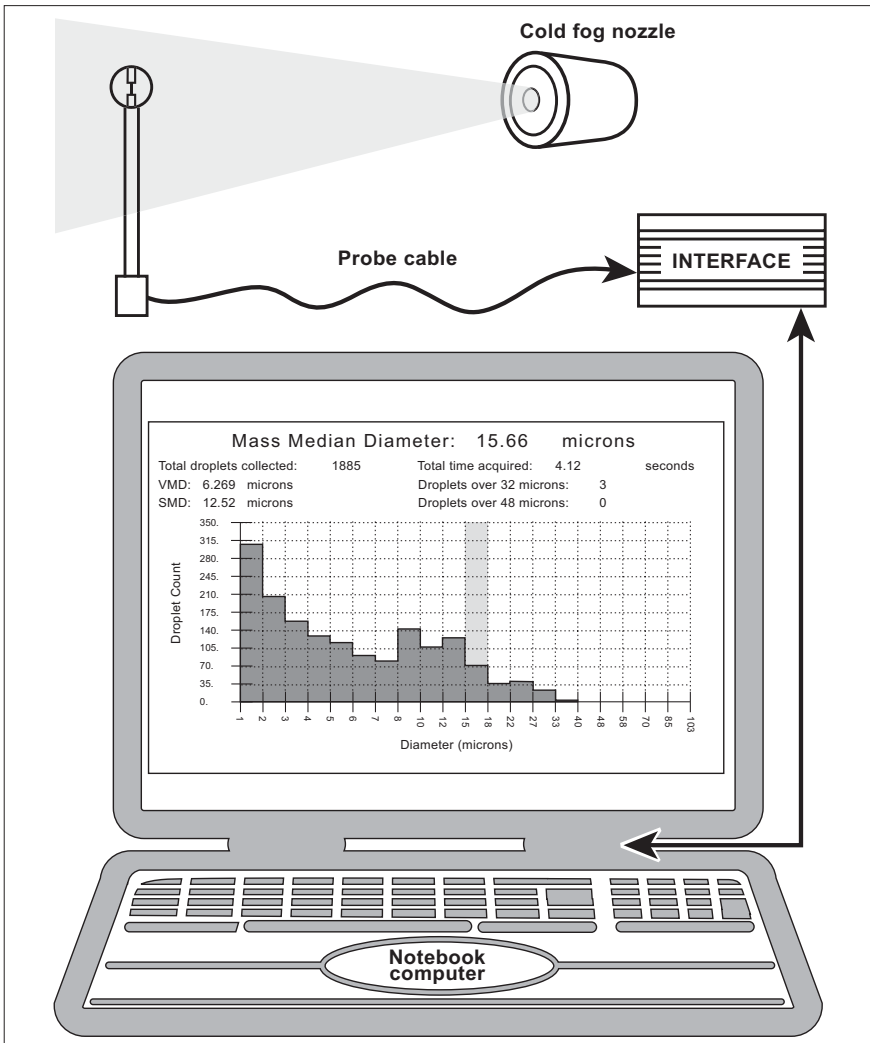


Figure 9. Hotwire anemometer

(20–200 μm) forms a crater that is 1.15 times larger than the true droplet size (the droplet spreads slightly on impact with the magnesium oxide). The reciprocal of the spread factor is used to convert the measurements of craters (or stains) to the true size. The spread factor of magnesium oxide is 0.86. However, with smaller insecticide droplets the spread factor is reduced to 0.8 and 0.75 for those measuring 15–20 μm and 10–15 μm , respectively. Magnesium oxide-coated slides are less satisfactory for droplets smaller than 10 μm , hence the need to swing the slide through the spray to increase impact velocity. The addition of a coloured dye facilitates observation of the droplets on the white surface.

Teflon®-coated slides can be reused but have to be washed with a solvent, e.g. acetone, to remove any traces of the previous sample.

A clip is used to attach the slide to a 1-metre long stick, to allow the person to stand to one side when waving it through the fog, at a distance of 1–2 metres from the nozzle.

The slide wave technique is not efficient at sampling small droplets. Slides may be fitted to a rotary device to increase the speed at which the slide samples the spray in order to improve sampling efficiency.

Usually five separate samples are taken and at least 200 droplets are measured under a microscope. A suitable graticule is placed in the eye-piece and calibrated with a stage micrometer for the magnification being used. The diameters of the craters produced by the droplets on the slide are measured by comparison with the graticule markings (Figure 10).

Table 3 illustrates the calculations needed to determine the VMD and NMD of a spray using a magnesium oxide-coated slide with a spread factor of 1.15. The ΣNdm^3 and ΣN , expressed as percentages, are plotted against the true droplet sizes, on logarithmic probability graph paper, to obtain these parameters (where Σ is the sum, N is the number in the size class, dm is the diameter of the droplets). In this specific example, the NMD and VMD are about 19 and 22 μm , respectively (Figure 11).

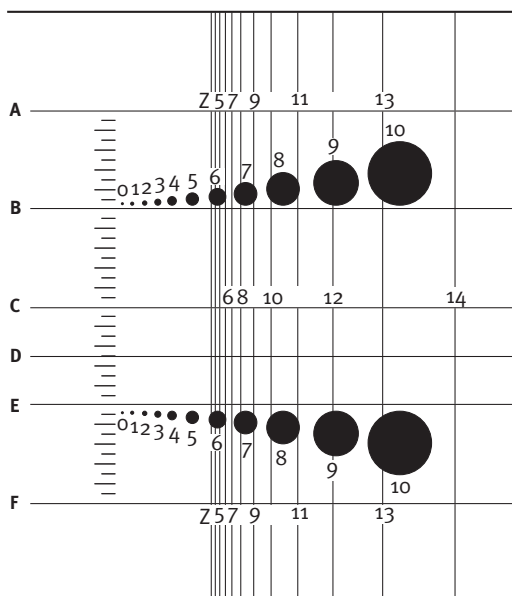


Figure 10. A graticule for measuring droplet size

Table 3. An example of the size distribution of spray droplets deposited on a glass slide

Graticule number	Upper class size (D)	True size limit (d)	Mean size (dm)	Number in class (N)	N (%)	ΣN (%)	dm ³	Ndm ³	Ndm ³ (%)	ΣNdm^3 (%)
4		12.80								
5		18	15.40	33	16.3	16.3	3652	120516	5.1	5.1
6		25.60	21.80	145	71.8	88.1	10360	1502200	63.0	68.1
7		36.25	30.90	23	11.4	99.5	29504	678592	28.5	96.6
8		51.25	43.75	1	0.5	100.0	83740	83740	3.5	100.1
9		72.50	61.90							
10		102.5	87.50							
11		145								
12		205								
13	250	290								

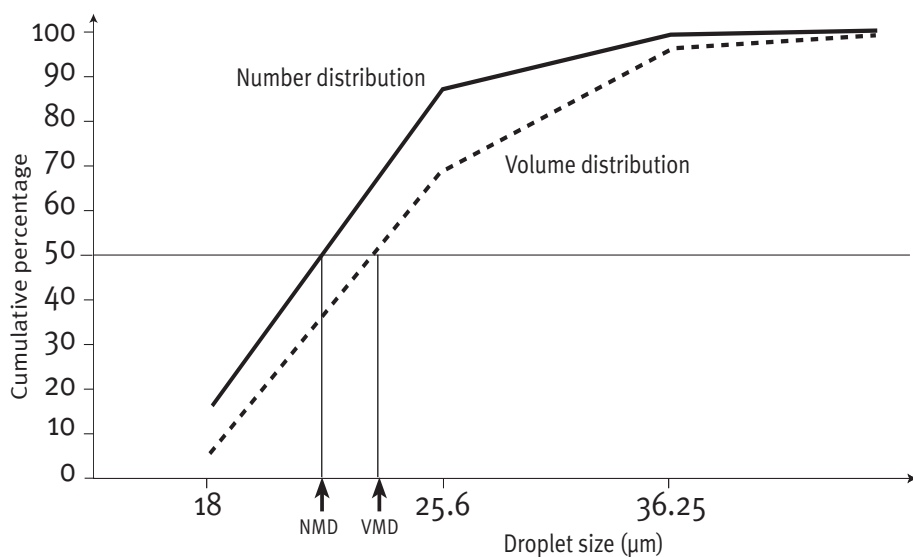


Figure 11. Number and volume distribution of droplets (data from Table 3)

Where water has been used to dilute the spray, water-sensitive paper strips can be used to collect droplets for sizing, but as the stains may increase in diameter over time, their use is indicative only of the size and is not as precise as other techniques. Treating the water-sensitive paper with ethyl acetate will make the stains more permanent. The spread factor varies according to the formulation and droplet size. Papers that are sensitive to oils and certain solvents can also be used.

6.2 Application procedures

6.2.1 Operator protection

All persons involved in the application of space sprays must wear overalls, protective gloves and goggles when pouring out insecticide, preparing a spray liquid and filling equipment (a semi-closed automatic dilution machine for use with water diluted spray is available). As the spray droplets are small enough to be inhaled, equipment operators must be issued with and wear a suitable respirator, the filter of which must be periodically changed in accordance with the manufacturer's instructions. Engine-driven equipment is very noisy so the operator should also wear ear protection. Equipment must have guards to prevent operators touching hot surfaces. Operators must work in accordance with national regulations on pesticide use and application and should strictly follow the recommendations of the manufacturer.

6.2.2 Indoor fogging

Personnel conducting this work require training on the safety measures to be followed. Several rules apply:

- Shut off all electricity at the master switch.
- Turn off all heating and cooking equipment, including pilot lights and allow for a cool down time before spraying.
- The risk of fire is less with water-diluted products.
- Protect all water containers and foodstuffs.
- Remove fish or cover fish tanks.
- Ensure all occupants and animals remain outside the house during spraying and stay outside for 30 minutes after spraying. Ensure that the building is ventilated before reoccupation.

- Close all doors and windows before spraying and keep them closed for 30 minutes after spraying to ensure maximum efficacy.
- Spray operators should work backwards and away from the fog to minimize exposure.
- For small single-storey houses, the spray can be delivered from the front door or through an open window without having to enter every room of the house, provided that adequate dispersal of the insecticide droplets can be achieved.
- For large single-storey buildings, it may be necessary to apply the spray room by room, beginning at the back of the building and working towards the front.
- For multi-storey buildings, spraying is carried out from top floor to the ground floor and from the back of the building to the front. This ensures that the operator has good visibility at all times.

The size of an average dwelling (in m²) should be calculated and the volume of the diluted spray required according to the manufacturers label recommendations (*note: some manufacturers' label recommendations for indoor fogging are given as rates per volume*). The flow rate of the machine (ml per minute) should be checked so that the average time required to spray each dwelling is known and the spray operators are informed.

A fog must be "dry" before being directed into a building. Test the fog by placing the machine on the ground and checking that the area immediately in front of the nozzle is not wetted by the fog. To reduce the production of large wetting droplets, obtain the correct balance between flow rate and combustion temperature. This is usually done by reducing the flow rate.

6.2.3 Outdoor ground fogging

Advanced route planning should precede outdoor ground fogging operations and may require a combination of vehicle-mounted and hand-carried or knapsack equipment in areas with difficult or limited vehicle access. Consideration must also be given to the following:

- Spraying should not be undertaken when it is raining, when winds exceed 15 km/hour, or in the heat of the day.
- Doors and windows of houses and other buildings should be open to allow penetration of the spray cloud for improved efficacy.
- For vehicle-mounted equipment, in areas where the roads are narrow

and the houses are close to the roadside, the spray should be directed backwards from the vehicle. In areas where the roads are wide, with buildings far from the roadside, the vehicle should be driven close to the roadside and the spray should be directed at an angle (downwind) to the road rather than directly behind the vehicle.

- The nozzle of vehicle-mounted cold fog machines may be directed upwards at an angle when there are barriers that impede airflow, e.g. boundary walls and fences; for vehicle-mounted thermal foggers, the nozzle should be directed horizontally.
- The distance between successive passes through a built-up area will be largely dependent on the layout of roads. A track spacing of 50 metres is generally recommended, with the vehicle moving upwind so that the fog drifts downwind away from it and the operators (Figure 12).

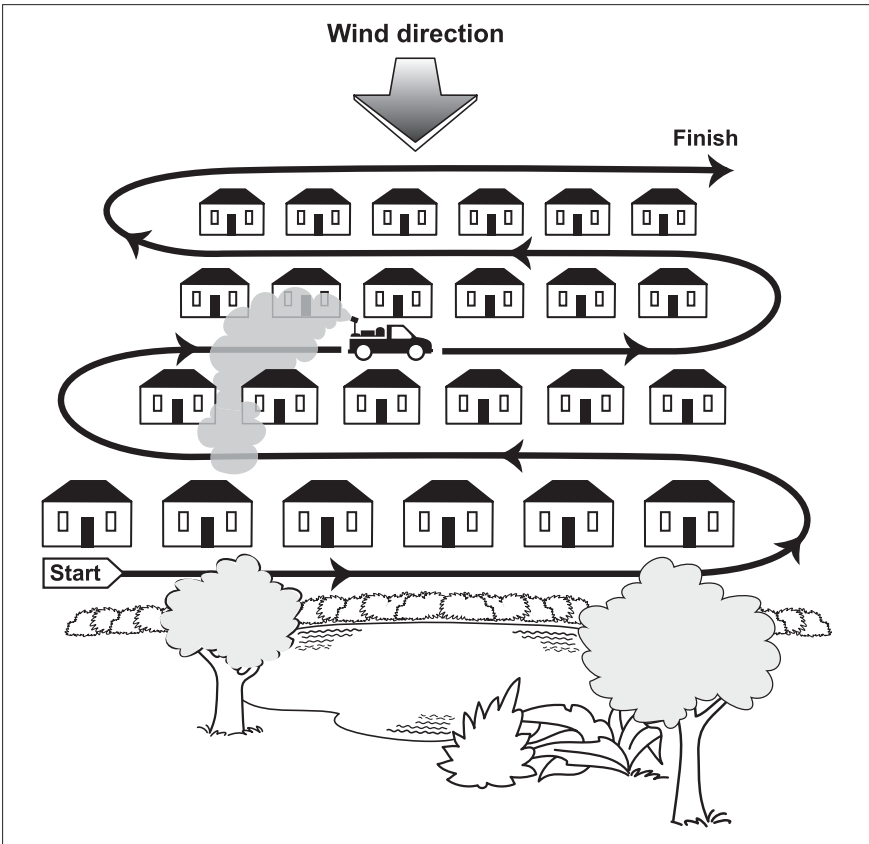


Figure 12. *Spray application route relative to wind direction in an urban setting. Coverage is from downwind to upwind. In this example, the first swathe targets flying adults in the proximity of the breeding site.*

- As far as possible, the predetermined speed of the vehicle should be maintained and the spray must be turned off when the vehicle is stationary.
- The downwind side of the spray area should be treated first, working systematically from downwind to upwind.
- To avoid driving into the spray cloud, dead-end roads must be sprayed only on the way out.
- Try to avoid directly spraying shrubbery and expensive floral areas unless using a water-based/water-diluted product.

6.2.4 Aerial application of fogs

Suppression of vector populations over large areas can be carried out using space sprays released from aircraft, especially over areas where access with ground equipment is difficult and extensive areas need to be treated very rapidly (Figure 13). In applying space sprays from the air, careful consideration must be given to meteorological factors, especially wind speed, at spray height and ground level, and the droplet size spectrum obtained at the flying speed of the aircraft. Treatments are often at night to take advantage of any inversion and to allow droplets to fall from a higher release height to where the disease vectors are flying.

Flying height is largely determined by operational factors, but droplet size, volatility of the formulation and flow rate need to be selected so that the droplets fall after release from the aircraft and are the correct size as they descend through the air space occupied by the disease vectors.

With aerial applications a combination of spray height, aircraft speed, wind speed and type of formulation affects the distance that the spray drifts downwind. Consequently an offset needs to be built in to spray applications. An offset is the distance upwind of the target area that spraying starts. This avoids downwind drift outside the target area. Similarly the finishing point must be the offset distance upwind of the upwind edge of the target area. The scope of this document does not permit the detailed description of how to calculate the offset. However, aerial spray contractors should be able to calculate the exact offsets.

For all air spray operations clearance must be obtained from the civil aviation authority. For safety reasons, operation over populated areas normally requires twin-engined aircraft. Modern aircraft are now fitted with global positioning systems so the exact position of the aircraft can be accurately recorded while insecticide is being applied.

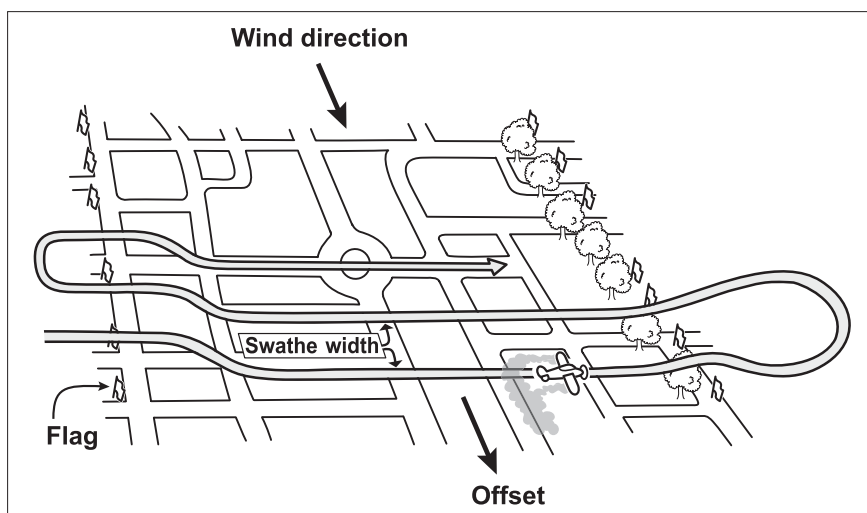


Figure 13. Aircraft spray application route relative to wind direction

6.3 Monitoring spraying operations

An operational log (daily report form) must be kept, showing pertinent data including the area treated, the date and time of application, meteorological conditions, type and amount of insecticide delivered and any operational difficulties encountered. The log must be regularly checked by the supervisor, who should record remarks on the performance of the equipment, malfunctions and hazards encountered. Examples of routine reporting forms are provided in Annexes 1–3.

Final reports for governing agencies must present an accurate picture of how equipment is functioning to determine its suitability and how the programme is progressing.

6.4 Evaluation

Evaluation of the efficacy of spray operations is carried out using techniques that are largely specific to the target insect. Space sprays are transient and only insects flying at the time of the application are affected. Therefore, adult populations can increase as a result of immigration from outside the treated area or emergence from a pupal population. Ento-

mological impact can be assessed either by comparing pre- and post-spray densities of the target insect or the mortality of caged insects, or by a combination of both methods (preferred). It should be noted that the mortality of caged insects is affected by cage design, material (including mesh size) and placement, the consequence of which may be an under-estimation of the efficacy of the spray and unwarranted dosage increase. On the other hand, high mortality rates of caged insects may result in over-estimation of the spray efficacy on the target population.

6.5 Equipment maintenance

Equipment operators and supervisors must be trained in the safe and proper use and routine daily checking and maintenance of the equipment. Adequate facilities and skills must also be on hand for regular servicing and repair of equipment and vehicles.

The recommendations in the equipment manufacturer's service manual must be followed carefully and a servicing record maintained. The efficient and effective performance of the machine is an integral part of achieving optimal performance.

The programme manager is responsible for ensuring that a supply of spare parts is included at the time of purchase of equipment and that an adequate supply is subsequently maintained. Each field operating unit should be provided with appropriate tools and enough supplies of spare parts for routine maintenance and repair.

When equipment is transported, it must be adequately protected against damage.

6.6 Pesticide storage and disposal

All insecticides used in space treatments should be stored in a safe, secure place and in accordance with manufacturer's label recommendations. Unused, diluted insecticide must not be left in the machine after fogging or stored. Empty containers and excess insecticide should be disposed of in accordance with national guidelines and regulations. Empty containers should be rendered useless before disposal.

7. Selected readings

Matthews GA (2000). *Pesticide application methods*, 3rd ed. Blackwell Science.

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Najera J, Zaim M (2002). *Malaria vector control: decision making criteria and procedures for judicious use of insecticides*. Geneva, World Health Organization (document WHO/CDS/WHOPES/2002.5).

WHO (1990). *Equipment for vector control*, 3rd ed. Geneva, World Health Organization.

ANNEX 1.

Daily application report

(portable and vehicle-mounted equipment)

- Date:
- Make and model of equipment:
- Serial number:
- Type and no. of nozzle:

- Locality and description of area sprayed (a map may be attached):

- Type of space spraying (thermal fogging/cold fogging):

- Wind velocity (km/h):
- Temperature (°C):
- Relative humidity (%):
- Time of application
 - Start:
 - Finish:
 - Total time of spraying:
- Insecticide used
 - Product name and concentration:
 - Amount of formulated product used:
 - Dilution rate and type of diluent:
 - Targeted application rate (ml/ha):
- Spray coverage
 - Area targeted (ha)
 - Area actually sprayed (ha):
 - Number of houses/rooms:

Vehicle-mounted equipment

- Vehicle speed (km/h):

- Remarks:

Name and signature of sprayman:

Supervisor: Name and signature and date:

Remarks:

ANNEX 2.

Maintenance record

■ Name, make and model of equipment: _____

■ Serial number: _____

Date	Total hours of use since last service	Details of breakdown	Repair: Parts fitted or replaced	Repaired by: Name and signature

ANNEX 3.

Routine machine performance check

- Date:
- Name, make and model of equipment:
- Serial number:

- Flow rate (ml/min)
 - Initial
 - After adjustment

- Droplet size
 - Initial
 - After adjustment

Physical check (condition of hoses, pipes, leakage, etc.) – comments:

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Name and signature of serviceman:

Name and signature of supervisor and date:

