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CHEMICAL APPLICATION

10

INTRODUCTION

The purpose of applying agricultural chemicals is to provide nutrients for plant growth and to control weeds, insects and other crop pests, and plant diseases. Proper application of agricultural chemicals is crucial in successful modern agriculture. Agricultural chemicals, over the years, have become more sophisticated but also more expensive, so good methods avoid over-application. The major classifications of agricultural chemicals are fertilizers, pesticides (including insecticides, which kill insects), herbicides (which kill plants), fungicides (which kill fungi), growth regulatory hormones, and pheromones for biological control of insects. These chemicals may be either dry or liquid. The chemicals may be applied before planting during seed bed preparation, during planting, and/or after germination during the active growth period.

In this chapter we will discuss the chemical application methods and related equipment, their functional components and operating principles, equipment calibration, testing, and other related topics.

10.1 APPLICATION OF GRANULAR CHEMICALS

Dry chemicals in agricultural use are primarily fertilizers, herbicides, and insecticides. Technically many of these are powders; however, powders that are large in particle size and flow easily—as is the case with these agricultural chemicals—are referred to as granular material. That is the term used in this book. There are some agricultural chemicals that are non-granular powders of small size, such as insecticide powders applied by dusters. Because of drift and poor coverage these are of limited use in commercial farming. Better choices include liquid pesticides or granular pesticides that are liquid chemicals impregnated on inert granular carriers such as clay, sand, or corncobs.

Application of dry granules has certain advantages. It eliminates the need to haul water and the mixing required with liquid chemicals. Chemical drift, i.e., droplets that do not land on the intended target, is generally not as great a problem as it can be with liquids. The application equipment is less expensive and more trouble-free since no mixing, pumping, and agitation is involved. While practicing conservation tillage, better control is possible with granules than sprays since granules filter through the foliage onto the soil. Also, granules are generally safer to use than liquid formulations.

However, granular material is generally more expensive than the liquid chemicals. Granular material has poor metering characteristics and uniform distribution is a problem. The use of granules is limited to soil applications as they require moisture to become activated. Granular pesticides must be kept in a dry place and they are more bulky to store and transport.

Traditional granular pesticide rates have been 12 to 24 kg/ha (15 to 30 lb/acre) with 5% to 15% active ingredient. With the availability of granular pesticides that are 20% to 50% active ingredient there is a trend toward lower rates of application. Some new formulations have 75% to 90% active ingredient with a recommended application rate as low as 1.12 kg/ha (1 lb/acre). With increases in the concentration of active ingredients, there has been a shift toward smaller granular particles. Smaller particles tend to give better coverage by increasing the number of particles per unit area, but they are more prone to drift.

10.1.1 Methods for application of granular chemicals

Granular fertilizer may be spread uniformly over the entire field, in a *broadcast application,* or it may be applied in narrow rows, which is called a *banded application*. It may be applied before planting, during planting, or in established crops.

Pre-planting applications include applying the material either on the soil surface or placing it below the surface using an appropriate tillage attachment. Material applied on the surface may be incorporated into the soil using an appropriate tillage tool (generally a field cultivator or a disk harrow) as part of normal seed bed preparation. Fertilizers may be placed deep into the soil with a chisel type cultivator. A fertilizer distributor may be used as an attachment to a plow that places it in the furrows below the surface at plowing depth.

Application during planting is commonly done by fertilizer drills. Hoppers, tubes, and furrow openers are built in the drills to place the fertilizer below and to the side of the seed rows. Similarly, row-crop planters have attachments to place fertilizers in a narrow band on either side of the seed row. The furrow openers for fertilizer are separate from the seed furrow openers and they can be adjusted independently in the vertical and horizontal directions.

Application in established crops puts chemicals either on the surface or below the surface of the soil. The method of application depends upon the crop and the planting type. In solid-planted crops, fertilizers may be surface applied using either a drop-type or a rotary spreader. In row crops, granular chemicals may be banded between the rows or applied on either side of the rows as *side dressing*.

10.1.2 Equipment for application of granular chemicals

The equipment for applying granular material includes drop-type (gravity), rotary (centrifugal), and pneumatic (air) spreaders. Equipment may be drawn behind tractors or mounted on trucks or aircraft.

Drop-type spreaders may be either for broadcast application or for banded application. A truck-mounted drop-type spreader for broadcast application with a 15.24 m (50 ft) boom is shown in Figure 10.1. Tractor drawn units have 2.4 to 3.7 m (8 to 12 ft) long hoppers with narrowly spaced openings in the bottom. The openings are gener-

Figure 10.1 – A drop-type fertilizer distributor (courtesy of Ag-Chem Equipment Co.).

ally 150 mm apart. A ground-wheel-driven shaft located inside the hopper near the bottom carries agitators to help flow the material. A slide gate is used to control the openings and to shut off flow during turnaround. A drop-type applicator for banded application is shown in Figure 10.2. This applicator utilizes several small hoppers as compared to one long one. The material is metered and dropped through a tube and is spread in a wide band by a diffuser. Some fertilizer distributors have furrow openers to place the material below the surface. This type of spreader is most commonly used as an attachment to planting equipment.

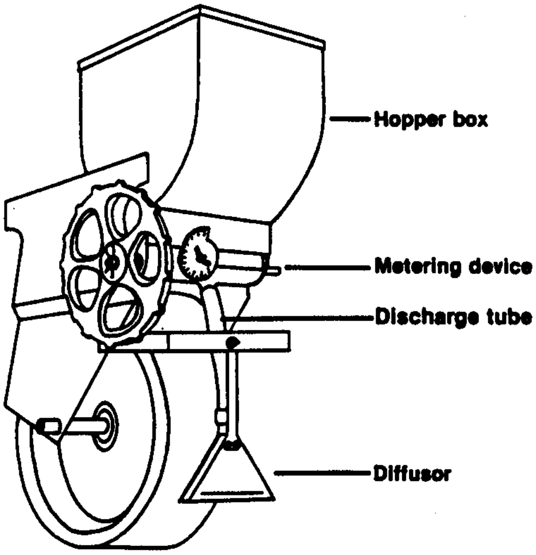


Figure 10.2 – A drop-type applicator for banded application (reprinted from Bode and Pearson, 1985).

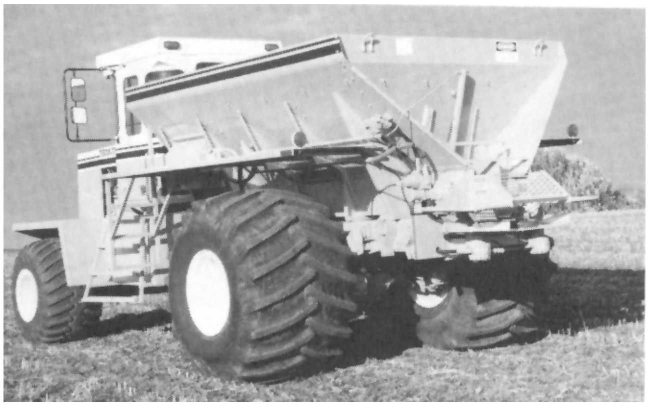


Figure 10.3 – A truck-mounted commercial rotary applicator (courtesy of Ag-Chem Equipment Co.).

Rotary spreaders are used for broadcast application. These spreaders have one or two rotating disks with multiple vanes to impart energy to the granules. The material is metered onto the disks and is thrown wide due to the centrifugal force. Rotary spreaders are generally tractor mounted, but some of the larger commercial units are truck mounted with twin spinners as shown in Figure 10.3. The trucks used for chemical application use high flotation tires.

Pneumatic applicators can be used for either broadcast or banded application. They have a centrally located hopper from which granules are metered, delivered by air through tubes across the width of the machine, and spread by being impinged onto deflector plates. Pneumatic applicators allow central tank filling, easier installation on tillage implements, improved distribution, and easier transporting of trailer mounted applicators. A pneumatic applicator is shown in Figure 10.4.

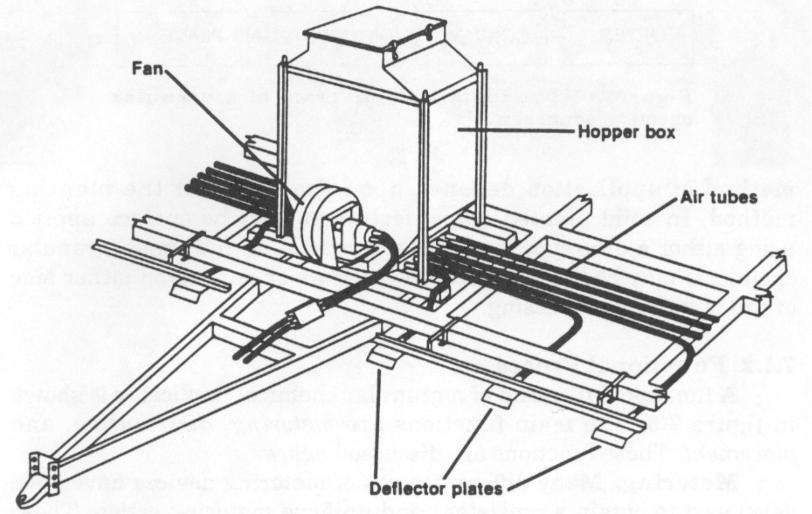


Figure 10.4 – A pneumatic applicator (reprinted from Bode and Pearson, 1985).

Aircraft are used to broadcast fertilizers in areas that are either too large or too difficult (rough terrain, flooded rice fields) for ground rigs. Airplanes carry a maximum payload of 500 to 1100 kg at working speeds of 130 to 190 km/h. The height of application usually varies from 9 to 15 m. *Ram-air spreaders* located underneath the fuselage consist of an air scoop, a venturi or restricted-throat section where the material is introduced, and a diverging section with dividers to give the proper lateral velocity components to the material being carried by the air streams. The air stream is generated by the propeller blast. Many ram-air spreaders give a trapezoidal distribution pattern that allows for a fairly uniform application with proper overlap at swath widths of 12 to 14 m. At application rates above 280 kg/ha (250 lb/acre) the particles are not accelerated properly and the distribution is not very uniform. The uniformity of application is also severely affected by crosswinds. Rotary spreaders are also used in aircraft applications. The spinners used in aerial applications rotate at a much faster speed as compared to the ground rigs in order to cover a much broader swath. Helicopters are used in areas where fixed-wing aircraft are not suitable, such as rugged, hilly terrain that is far away from a suitable landing site. The operating cost of helicopters is 2 to 3 times higher compared to fixed-wing aircraft.

10.1.3 Functional processes of granular chemical applications

A functional diagram of a granular chemical applicator is shown in Figure 10.5. The main functions are *metering, conveying, distribution*, and *placement*. These functions are discussed below.

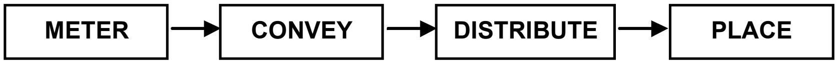


Figure 10.5 – The functional diagram of a granular chemical applicator.

10.1.3.1 Metering

Many different types of devices have been developed to obtain a consistent and uniform metering of granular chemicals. These devices are generally driven by a ground wheel that stops metering when the implement is stopped or lifted off the ground. Metering devices may be divided into *positive flow* and *gravity flow*. Positive flow metering devices provide for more accurate metering because a cavity is used to meter a certain volume of fertilizer (or other material). The rate of movement of the cavity determines the metering rate. Gravity flow devices rely on the orifice size to meter the flow rate. These differences are discussed in the following sections.

The *star-wheel feed* metering device (Figure 10.6) is used on some grain drills and a few row crop side-dressing attachments. Fertilizer, carried between the teeth of the feed wheel, falls into the delivery tube by gravity while material carried on top of the wheel is scraped off into the delivery opening. The discharge rate is controlled by raising or lowering a gate above the wheel.

Metering devices for some row-crop attachments have horizontal *rotating bottom plates* that fit up against the stationary bottom ring of the hopper base (Figure 10.7). The discharge rate is controlled by an adjustable gate over a side outlet. Sometimes there are two outlets permitting two bands from one hopper.

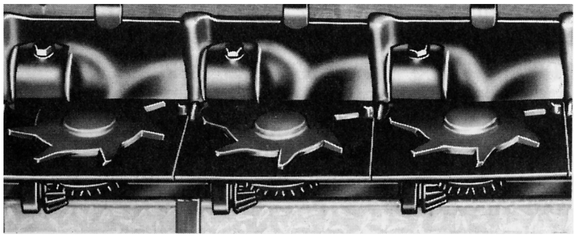


Figure 10.6 – Star wheel metering mechanism of a grain drill (reprinted from Kepner et al., 1978).

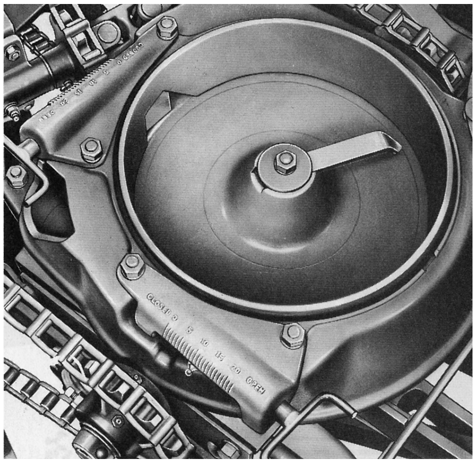


Figure 10.7 – A rotating bottom metering device (reprinted from Kepner et al., 1978).

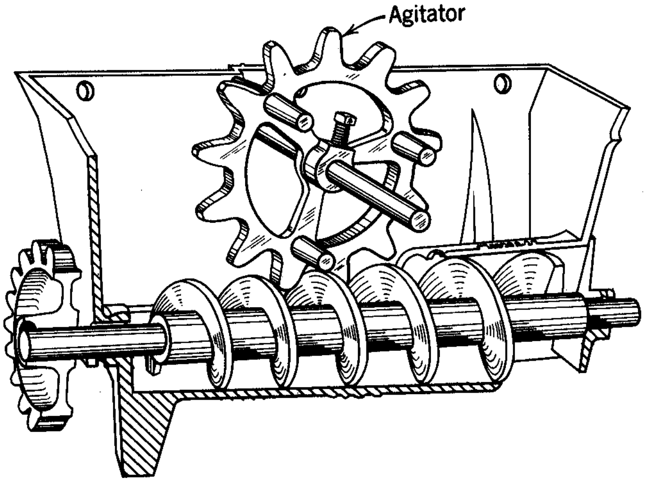


Figure 10.8 – A metering device with close fitting auger (reprinted from Kepner et al., 1978).

Auger-type metering devices are illustrated in Figures 10.8 and 10.9. The type shown in Figure 10.8 has a close-fitting auger tube and the auger has relatively large displacement per revolution. The loose-fitting or floating-auger arrangement shown in Figure 10.9a is widely used on row-crop attachments. The inside diameter of the tube is about 12.5 mm greater than the auger diameter. Each of the two auger sections move the material toward one end of the hopper, where it is discharged from the end of the tube or dropped through an outlet opening. One hopper serves two rows. Augers are easily removed for cleaning.

Figure 10.9b shows a variation of the *loose-fitting auger* principle in which the material enters the auger tube from the top instead of from the end, is transported a short distance through the chute, and is then discharged from a bottom outlet. The tube assembly forms the bottom of the hopper and is removable. A series of openings along the tube provide multiple outlets for row crop use or for drop-type broadcasters. With any of the auger-type metering devices, the discharge rate is adjusted by changing the speed ratio between the auger and the ground wheel.

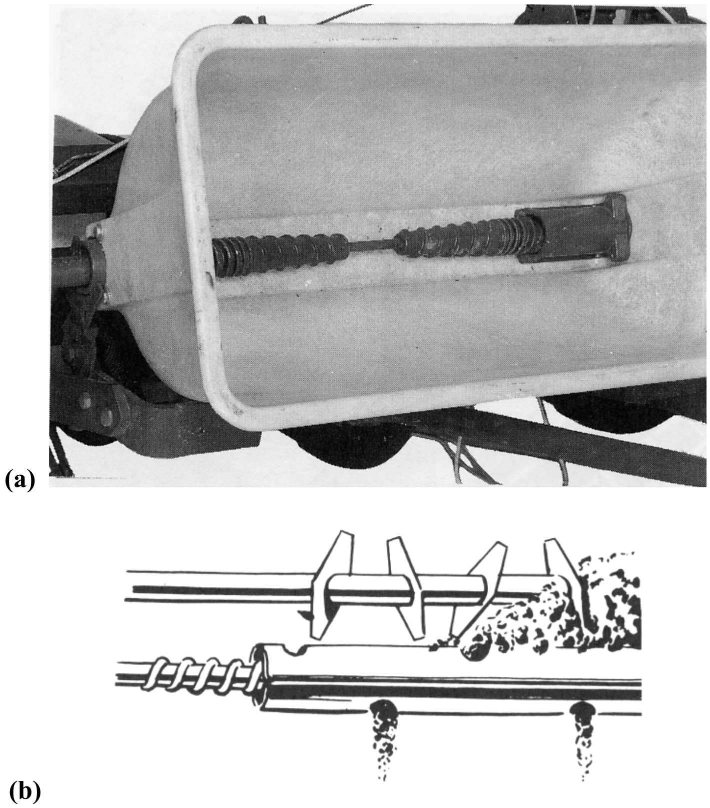


Figure 10.9 – Metering devices with loose-fitting auger (a) for row-crop attachments, (b) for row-crop attachment or drop-type broadcasters (reprinted from Kepner et al., 1978).

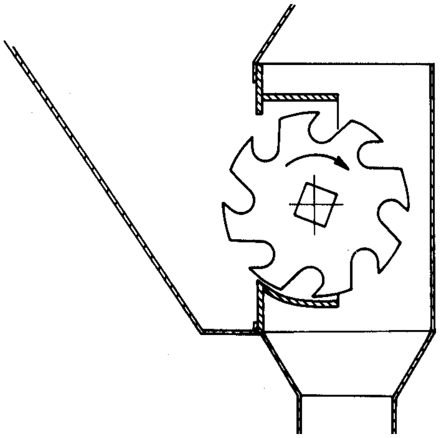


Figure 10.10 – An edge-cell vertical rotor metering device (reprinted from Kepner et al., 1978).

An *edge-cell, positive-feed metering device* is shown in Figure 10.10. Metering wheel assemblies are spaced as required along the hopper and are driven by a common shaft. Rotor widths ranging from 6 mm to 32 mm are employed for different rate ranges. The discharge rate for a given rotor is controlled by changing the rotor speed.

Belt-type metering devices are sometimes employed where relatively large application rates are required, as on rotary broadcasters with large hoppers. Some units have a flat wire belt (usually stainless steel) that drags the material along the hopper bottom (Figure 10.11) and others employ rubberized fabric belts. The discharge rate is controlled by an adjustable gate above the belt. The discharge can be split into two or more streams if desired.

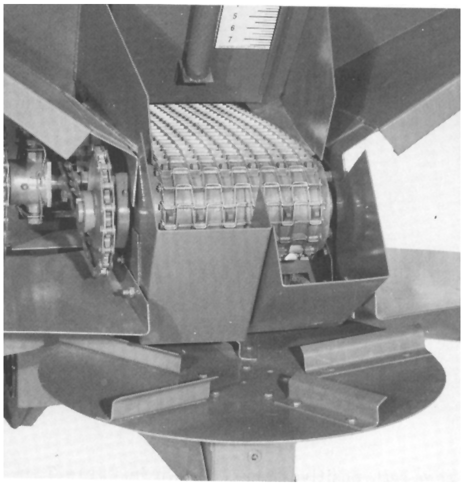


Figure 10.11 – A wire-belt metering device on a centrifugal broadcaster (reprinted from Kepner et al., 1978).

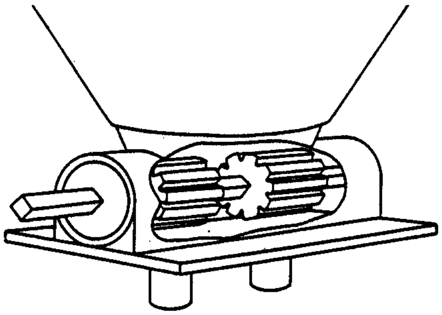


Figure 10.12 – A positive feed fluted roll type metering device (reprinted from Bode and Pearson, 1985).

Fluted metering devices are used for most granular-pesticide applicators. They consist of a ground-driven *vaned* or *fluted rotor* above an adjustable discharge opening (Figure 10.12). Hoppers for row crops sometimes have two or four openings whose outputs can be used separately or combined. Rotors fit closely in the hopper bottoms thus providing positive shut-off when the rotor is not turning.

Ideally, the discharge rate should be proportional to the rotor speed so that the application rate will not be affected by the forward speed. Tests have shown that this is not the case. Also, discharge rates are not proportional to the forward speed. This is due to incomplete filling of the inter-vane cavities, which is affected by the material flow characteristics. Fluted metering devices, like many other devices, produce a cycle variation in the uniformity of the application rate.

Gravity flow metering devices are common on drop-type broadcasters (Figure 10.13). In gravity flow devices, as opposed to the various positive flow metering devices discussed above, the metering rate is controlled by adjusting the size of the openings. A rotating agitator breaks up lumps and moves the material across the opening to assist in feeding. Rotating broadcasters have hoppers of a size that can be tapered down to a small bottom area and usually employ stationary-opening metering devices. Gravity metering devices are sensitive to ground speed.

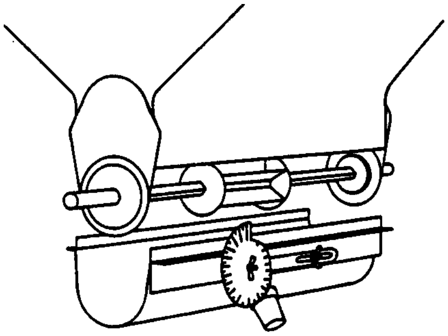


Figure 10.13 – A gravity flow metering device (reprinted from Bode and Pearson, 1985).

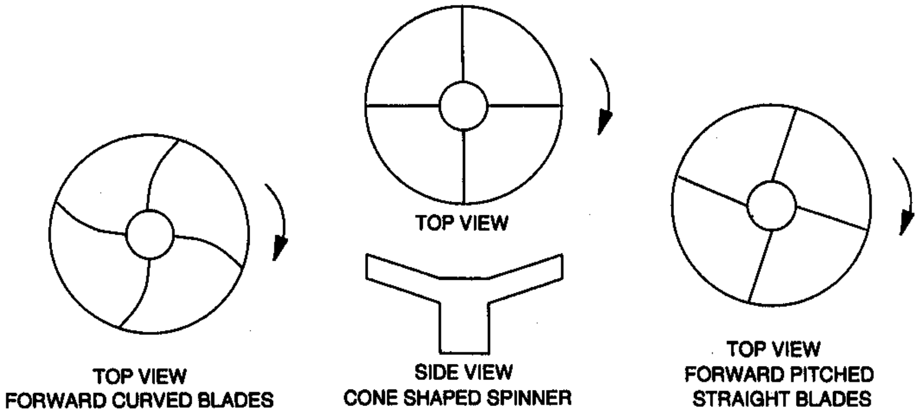


Figure 10.14 – Different types of spinners for rotary spreaders.

10.1.3.2 Distribution

Devices to distribute dry chemicals are of three main types: rotary, gravity, and ram-air spreaders.

Rotary spreaders usually consist of a single or a double counter-rotating horizontal spinner. The direction of rotation is such that the adjacent sides in the counter-rotating spinners move the material rearward. The spinners have blades that may be radial, forward pitched, or rearward pitched with respect to the radius. The blades may be either straight or curved. Forward-pitched blades give greater carrying distances for free-flowing materials, while rearward-pitched blades unload sticky material (e.g., moist lime) more readily. These spinners are shown in Figure 10.14. Rotary spreaders are used with broadcast types of applicators. A stream of granular material is dropped on the spinner and is thrown out by the action of centrifugal force. For a double spinner the stream is usually split in two by an inverted v-shaped splitter.

Gravity diffusers are made of an inverted v-shaped housing made of either plastic or sheet metal at the bottom of the drop tube. The housing has distributing vanes or other parts that take the stream of granular material and distribute it evenly into a wide band. Unlike rotary spreaders, the gravity type diffusers apply chemicals in more controlled manner and, therefore, they are more suitable as attachments to row-crop planters and cultivators. They are also available in open field fertilizer drills for full coverage of the field. Figure 10.15 shows various gravity type diffusers.

Ram-air spreaders are found in aircraft equipment. These are located in the propeller blast beneath the fuselage. A spreader of this type consists of an air scoop, a venturi or restricted-throat section where the material is introduced, and a diverging section with dividers to give the proper lateral velocity components to the material being carried by the air streams. Many different designs of the ram-air distributors have been developed. Most of those for spreading fertilizers or seeds are 910 to 1140 mm long, have a throat 610 to 760 mm wide and 150 to 200 mm high, and have a discharge area at least twice the throat area. The discharge angle for the outer sections is usually at least 45° from the line of travel.

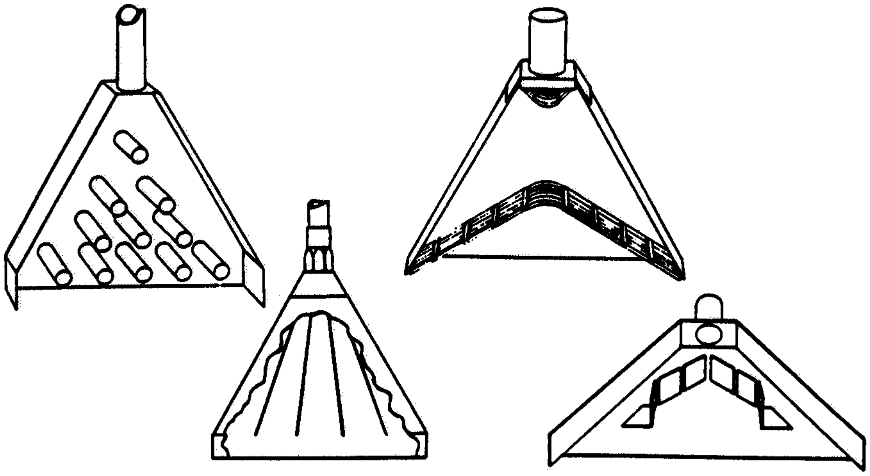


Figure 10.15 – Various types of diffusers used in drop-type applicators (reprinted from Bode and Pearson, 1985).

Many of the ram-air spreaders give a trapezoidal distribution pattern with a fairly flat top so that reasonably uniform distribution can be obtained with proper overlap at swath width of 12 to 14 m. However, as the material flow rate increases, the air velocity through the spreader is decreased and there is less energy available to accelerate the particles. Consequently, distribution patterns are poor for discharge rates greater than 900 kg/min. Another limitation of the ram-air distributors is the high aerodynamic drag and power requirement (Yates and Akesson, 1973).

Uniformity of coverage is one of the most important performance criteria. The horizontal distance through which the particles are thrown is affected by the particle size, density, and shape in addition to the spinner speed and geometric configuration. The components of a dry blend tend to separate as the larger particles of the same density travel farther. Wind also affects the carrying distance, and hence, the distribution pattern.

Uniformity of application is influenced by the shape of the pattern from the spreader and by the amount of overlap. Most patterns from rotary spreaders can be approximated by one of the shapes shown in Figure 9.17 (Chapter 9). Theoretically, pyramid, flat-top, and oval patterns give a uniform distribution if they are symmetrical, straight-sided, and overlapped as shown. The pyramid pattern allows more leeway for driving error. Humped patterns are undesirable from the standpoint of uniformity, but of the shapes shown would give reasonably uniform distribution, if the swath width were not over 40% of the overall pattern width, or if there were 60% overlap.

10.1.3.3 Placement

Placement devices may apply the chemical on the surface or below the surface. Surface applications are often incorporated into soil by a tillage tool if done before planting. On growing crops, especially solid-planted crops, a chemical is nearly always applied as top dressing and not incorporated into the soil. Fertilizer may be placed below the surface by a planter or a cultivator, or placed deep in the soil using chisel plows, or drilled into established pastures and other sods with special equipment.

Banded placement during row-crop planting is accomplished with applicators that are independent from the seed furrow opener. Double-disk, single-disk, and runner-type openers, similar to seed furrow openers, are often used.

Fertilizer grain drills often deliver the fertilizer through the seed tube, placing it in direct contact with the seeds in furrow. Separate disk openers are sometimes provided in front of the seed openers so that the seed row is not disturbed.

10.2 APPLICATION OF LIQUID CHEMICALS

Liquid chemicals include fertilizers, herbicides, pesticides, and growth-regulating hormones. These may be water emulsions, solutions, or suspensions of wettable powders. Liquid pesticides may be either *contact* or *systemic* type. Contact pesticides kill insects, fungi, etc., by coming in contact. To be effective, full coverage of the target, normally achieved by smaller droplets, is necessary. Systemic pesticides are taken in by the plant and they translocate within the plant. Full coverage of the plant is not required and larger droplets that are less prone to drift are acceptable.

10.2.1 Methods for application of liquid chemicals

Liquid chemical application methods vary depending on whether they are applied pre-planting, during planting, or post-planting. Pre-planting applications generally are fertilizers and herbicides and may include subsurface or surface application. Applications of aqua ammonia and anhydrous ammonia fertilizers are usually subsurface. Their application is accomplished by means of specially designed knives or chisel injectors. Liquid chemicals applied during planting generally include fertilizers and herbicides. Post-planting chemical applications may include fertilizers and all types of pesticides.

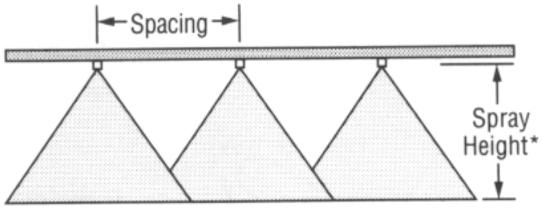
Liquid chemical application methods may be further divided based on the area covered. This may be *broadcast*, *banded*, and *directed spray*. In a broadcast application the chemical is applied uniformly on the ground or on the crop. In banded application the chemical is applied in narrow bands or strips. Several nozzles are used in directed spray for row-crop applications for a more complete coverage of the plants. Figure 10.16 shows the three methods of application.

10.2.2 Equipment for application of liquid chemicals

10.2.2.1 Sub-surface application

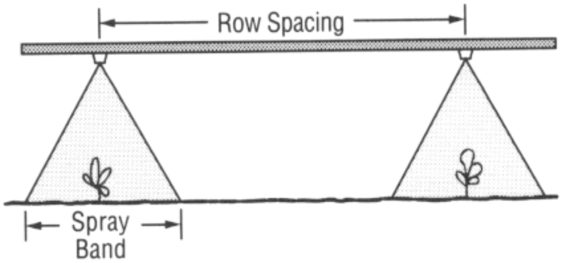
Sub-surface application is generally used for liquid chemical fertilizer in the form of anhydrous ammonia or aqua ammonia. These are called *pressure liquids* because they have a high vapor pressure that is used to create flow. *Anhydrous ammonia* contains 82% nitrogen and its boiling point is –28° F. When water is added to anhydrous ammonia to reduce the vapor pressure it is called *aqua ammonia*. It contains only 20% to 25% nitrogen, has a higher boiling point, and is termed *low pressure liquid fertilizer*.

With anhydrous ammonia, aqua ammonia (as well as other liquids with high vapor pressures), it is essential that the material be released in narrow furrows and

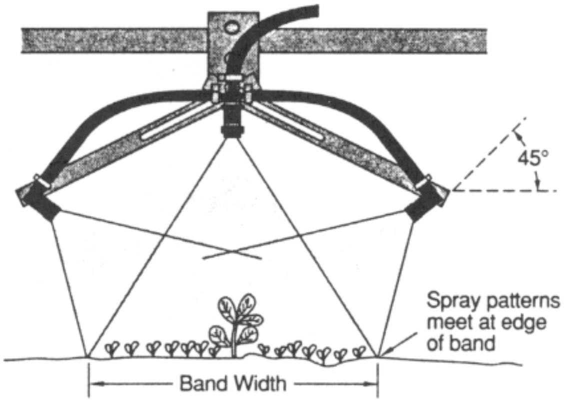


* Adjust spray height in the field to overlap approximately 30% of each edge of pattern.

Broadcast



Banded



Directed

Figure 10.16 – Methods of liquid chemical application (courtesy of Spraying Systems Co., 1991).

covered immediately to prevent escape. Anhydrous ammonia should be released at a depth of at least 10 to 15 cm. Aqua ammonia is applied about 5 cm below the surface since it is not as volatile. A loose, friable soil with adequate moisture is important for good sealing and for absorption of ammonia on the soil particles. Under some conditions press wheels or some other covering devices follow immediately behind the applicators.

Figure 10.17 shows a schematic of a trailing ammonia applicator. Note that there is no pump in the system, as the vapor pressure of the ammonia is used to pump the liquid. A regulator valve is needed to control the flow as the vapor pressure varies with the amount and concentration of ammonia in the tank and with temperature. For example, at 15.6° C the vapor pressure is 620 kPa (93 psi) but at 37.8° C the pressure rises to 1.3 MPa (197 psi). For subsurface application of aqua ammonia a pump is necessary because of its lower vapor pressure.

A typical narrow applicator blade for sub-surface applications is shown in Figure 10.18. The liquid is discharged from holes in the sides of the delivery tubes near the lower end. The spacing of the knives depends on the crop being grown.

Ground driven, variable stroke pumps are also employed to meter ammonia. Both mounted and pull-type implements are available for applying pressure liquids.

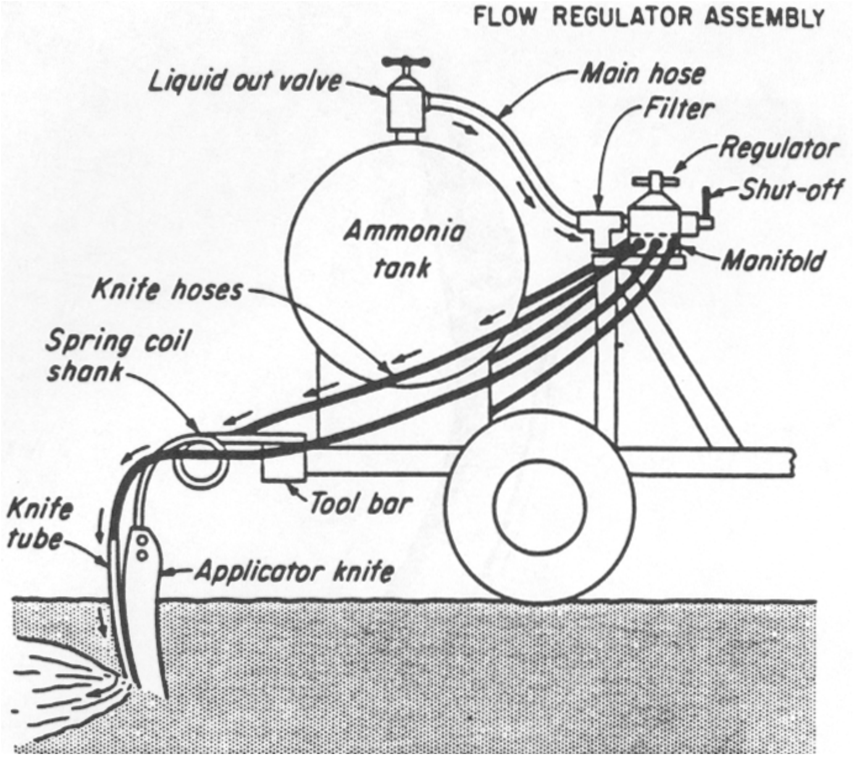


Figure 10.17 – A schematic of a trailing ammonia applicator (reproduced from Smith, 1964, by permission of McGraw-Hill Book Co.).

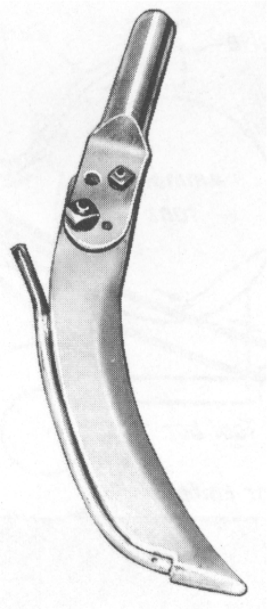


Figure 10.18 – An applicator blade for anhydrous ammonia (reprinted from Kepner et al., 1978).

10.2.2.2 Application of non-pressure liquids

In *non-pressure-liquid applicators*, the flow of liquid is due to gravity and the flow rate is controlled by fixed orifices. The attachments generally have a sediment bowl, a filter, one or two orifice disks with a range of orifice sizes, and a quick shut-off valve. Unless the tank elevation is large in relation to its depth, or bottom venting is employed, head changes will cause appreciable variations in flow rate. Bottom venting (inverted siphon) is obtained by having the tank sealed such that air can enter only through an open tube that runs from the top of the tank to a point inside the tank near the bottom. The height of the bottom end of the tube in relation to the orifice then establishes the liquid head. This tube may be attached to a sealing-type filler cap. With a given orifice size and head, the application rate per hectare is inversely proportional to the forward speed.

A simple squeeze pump as shown in Figure 10.19 has been developed for many non-pressure-liquid applicators. Units are available with as many as 20 tubes, each serving one applicator outlet. The positive-displacement, ground-wheel-driven pump produces flow rate proportional to ground speed. The application rate is adjusted by changing the speed ratio between the reel and the ground wheel.

Non-pressure liquids can be applied directly to the soil surface, as well as on pasture and other solid-planted crops. Banded application of non-pressure liquids are sometimes made during a row-crop planting operation or as later side dressing. Non-pressure liquid chemicals are available for many planters. Usually one tank is provided for each two rows. Liquid is discharged close to the furrow through small tubes.

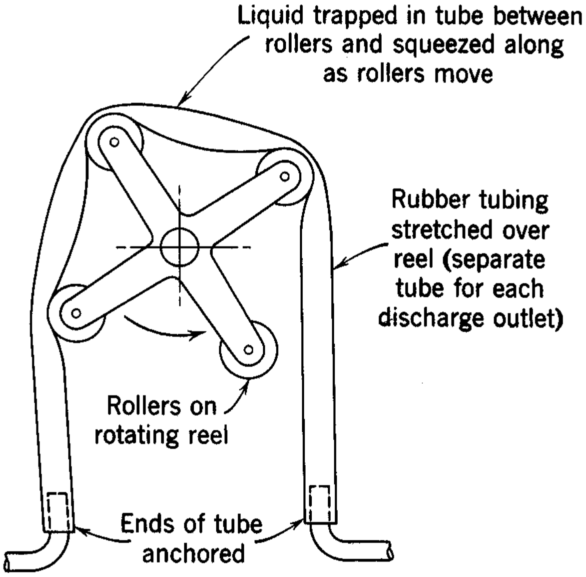


Figure 10.19 – A squeeze pump (reprinted from Kepner et al., 1978).

10.2.2.3 Low-pressure sprayers

Low-pressure sprayers are used to apply pre- and post- emergent chemicals to control weeds, insects, and diseases. Boom-type sprayers are used on tractors, trucks, or trailers; a tractor-mounted boom-type of field sprayer is shown in Figure 10.20. Low-pressure units usually operate in 150 to 350 kPa range and apply 50 to 200 L/ha. However, in some ultra low volume (ULV) applications, the rates may be as low as 10 L/ha to a few mL/ha. Tank-on-tractor mounted sprayers hold from 575 to 1000 L. For application in the standing row crop, high-clearance sprayers have been developed. They have a frame high enough to clear corn, cotton, and other tall crops. The spray boom may be raised or lowered depending upon the crop height. The sprayer may be mounted on a trailer or wheels and pulled through the field by a tractor. Tank capacity may be as high as 3750 L. The boom width may vary from 4 to12 m. Skid-mounted sprayers may be placed on a pickup truck or a flatbed truck. The tank size may be up to 10,000 L and the boom width up to 18 m. The trucks are fitted with flotation tires so they can operate in wet conditions.

Aircraft-mounted low-pressure sprayers have the advantage of rapid coverage and applying chemicals when conditions are otherwise unsuitable for ground rigs. Because of the limited weight carrying capacities, aircraft-mounted sprayers are most suited for low application rates of less than 50 L/ha. The aircraft speed varies between 50 to 125 km/h for helicopters and 175 to 250 km/h for airplanes as they fly about 1 to 8 m above the crop height.

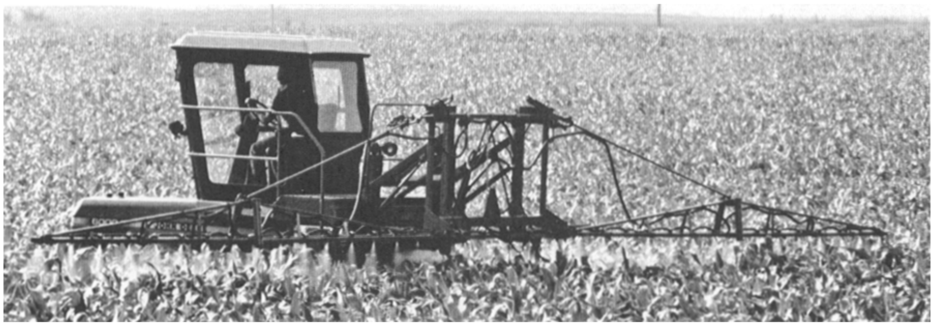


Figure 10.20 – A boom-type field sprayer (reproduced by permission of Deere and Co., © 1991. All rights reserved).

10.2.2.4 High-pressure sprayers

High-pressure sprayers are similar to low-pressure sprayers except they operate under much higher pressure, up to 7000 kPa, and generally do not have a boom with multiple nozzles. High-pressure sprayers are used in orchards where it is necessary to spray to the top of the trees and to penetrate the thick tree canopy. High-pressure sprayers are more expensive because the parts are made to withstand higher pressures.

10.2.2.5 Air-carrier sprayers

Air-carrier sprayers are sometimes called *air-blast sprayers* or *mist blowers*. The liquid is atomized either by pressure nozzles or rotary atomizers in a high velocity air stream. The atomized liquid is then carried to the target by the air stream. The sprayers are capable of generating air flow rates in the range of 2.5 to 30 m^3/s with air speeds ranging from 125 to 240 km/h. Since air is used to carry the pesticide to the target, concentrated pesticides can be used resulting in a substantial savings in the amount of water needed and the time required for refilling. Two different types of air-carrier sprayers are shown in Figures 10.21 and 10.22.

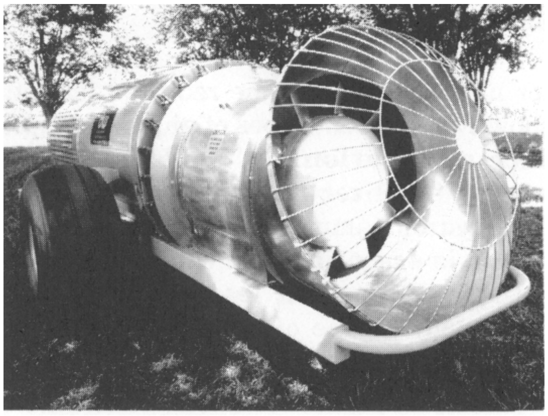


Figure 10.21 – An air-blast sprayer (courtesy of Durand-Wayland, Inc.).

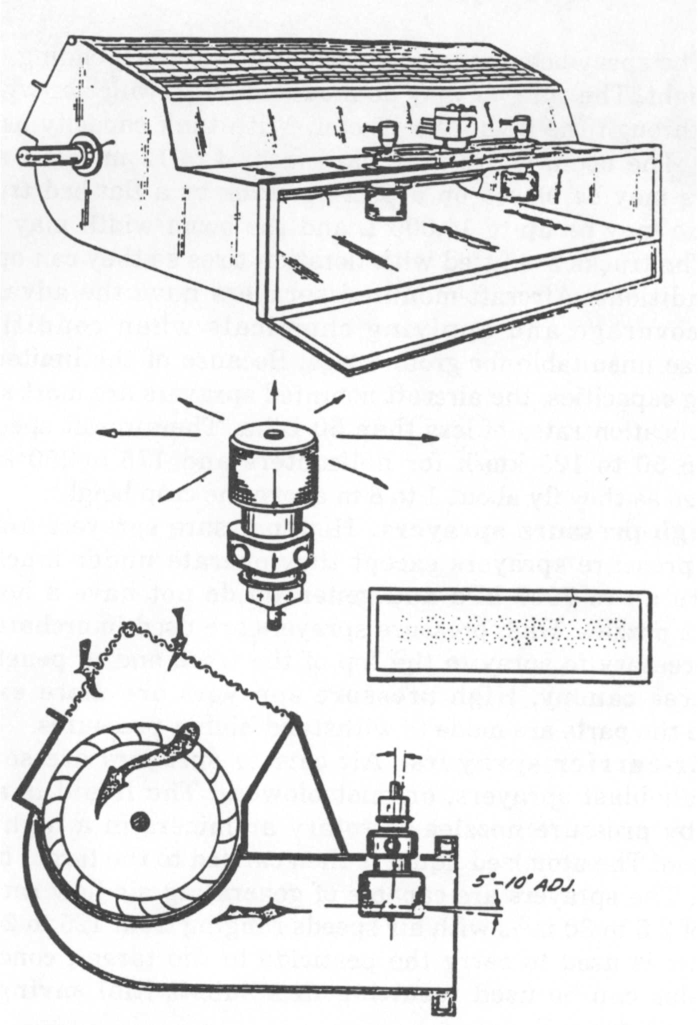


Figure 10.22 – An air-curtain sprayer utilizing a cross-flow fan and a rotary controlled droplet atomizer (Van Ee and Ledebuhr, 1987).

10.2.3 Functional processes of applying liquid chemicals

Figure 10.23 shows two typical arrangements for a hydraulic sprayer. A hydraulic sprayer consists of a tank to hold the liquid chemical, an agitation system to keep the chemical well mixed and uniform, a pump to create flow, a pressure regulator valve to control rate of flow, a series of nozzles to atomize the liquid, and miscellaneous components such as boom, shut-off valves, fittings and strainers.

The main functional processes—pumping, agitation, and atomization—are discussed below.

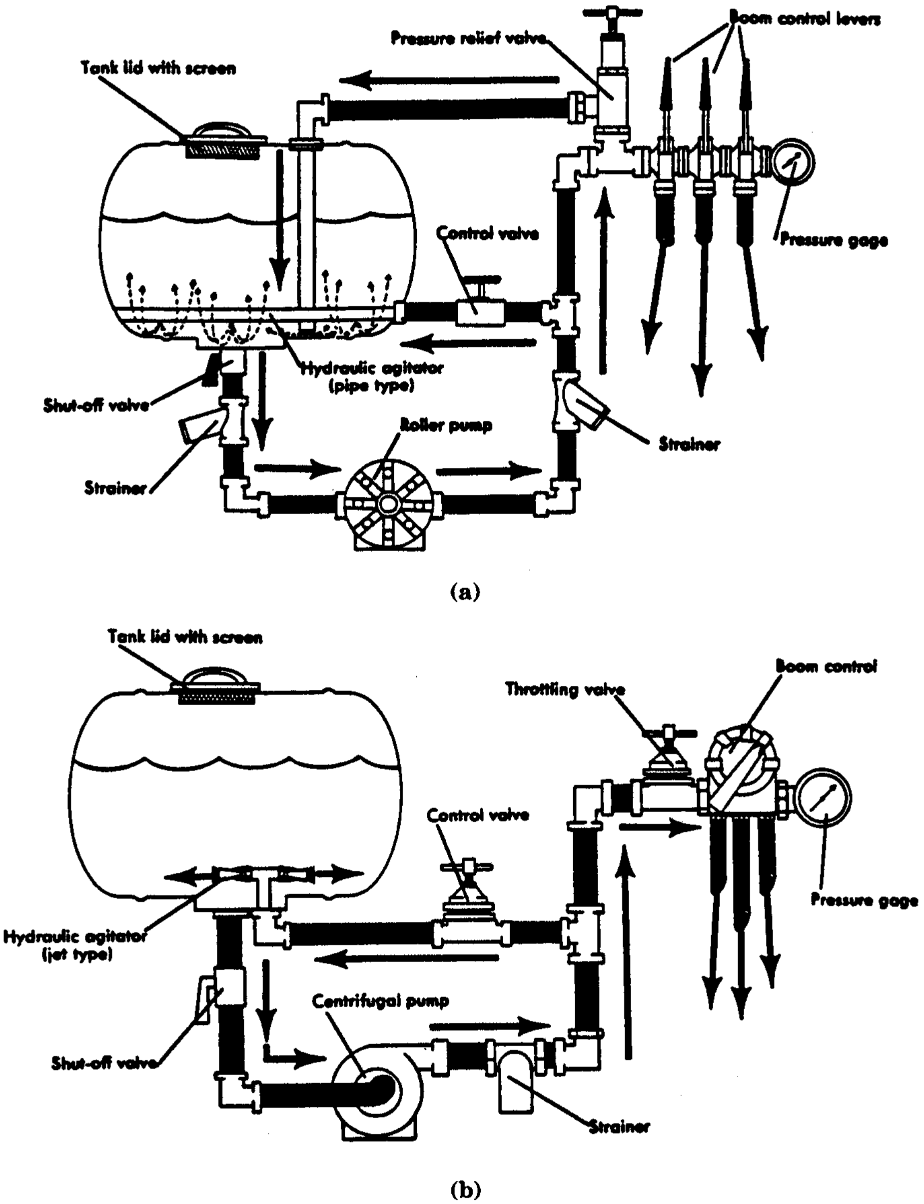


Figure 10.23 – Schematic diagrams of low-pressure hydraulic sprayers utilizing (a) a roller pump, (b) a centrifugal pump (reprinted from Bode and Butler, 1981).

10.2.3.1 Pumping

Positive-displacement pumps. With *positive-displacement pumps*, the output is not affected by the output pressure and the flow is created by positively displacing a volume by a mechanical means such as a piston or plunger. In contrast, with a *centrifugal pump*, flow is created by the action of centrifugal force. The output drops as the output pressure is increased.

Positive-displacement pumps found on sprayers include piston (plunger), rotary, and diaphragm types. These are self-priming, and they all require automatic (spring-loaded) bypass valves to control the pressure and to protect the equipment against mechanical damage if the flow is shut off.

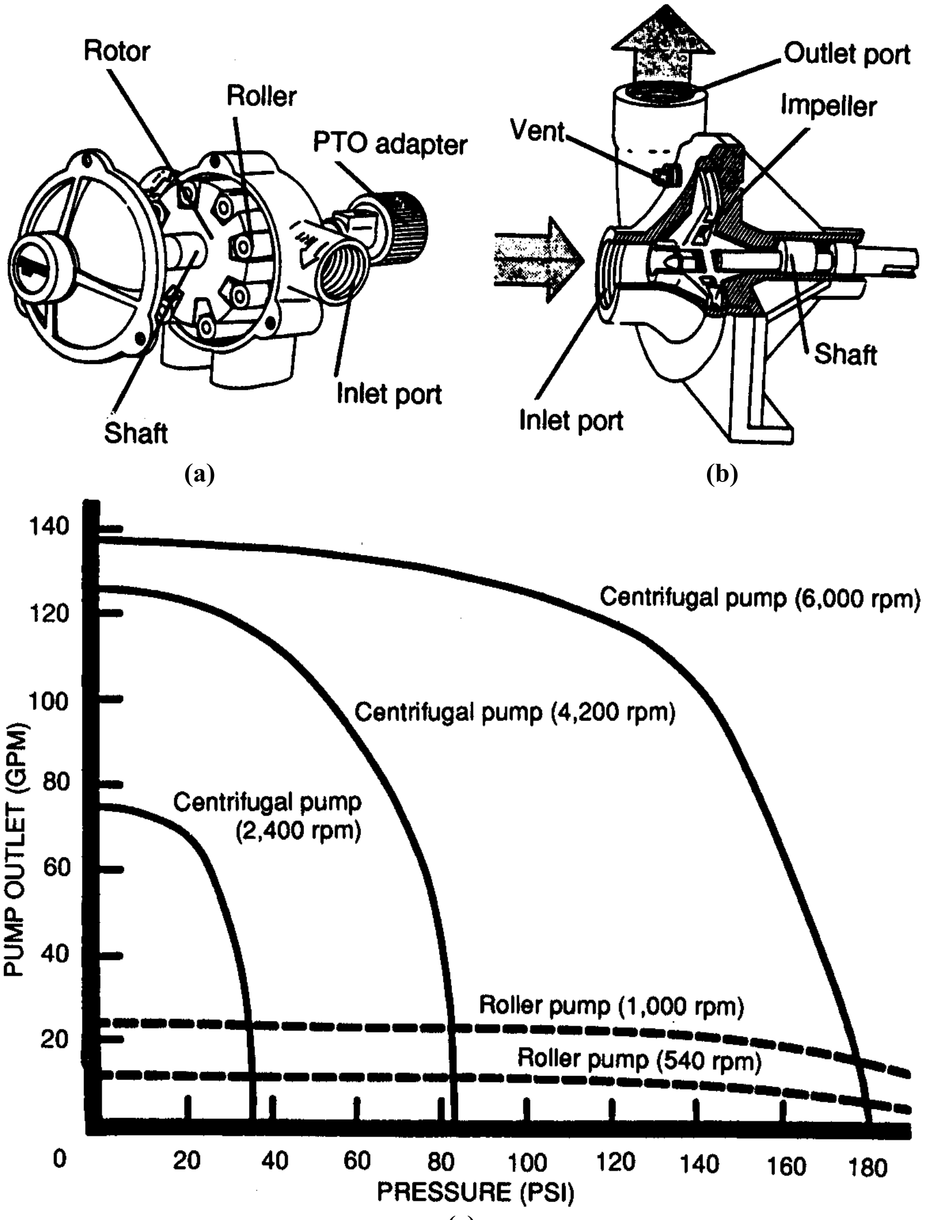
Piston (plunger) pumps are a kind of positive-displacement pump that is well suited for high-pressure applications such as high-pressure orchard sprayers and multipurpose sprayers designed for both high- and low- pressure spraying. They are more expensive than other types, occupy more space, and are heavy, but they are durable and can be constructed so they will handle abrasive materials without excessive wear.

The volumetric efficiency of a piston pump in good condition is generally high (90% or more), and the discharge rate is essentially a direct function of crank speed and volumetric displacement. Crank speeds on the smaller piston sprayer pumps [38 L/min (10 gpm) and less] are mostly 400 to 600 rev/min. High-pressure piston sprayer pumps [4.1 to 5.5 MPa (600 to 800 psi)] are usually operated at 125 to 300 rev/min have capacities of 75 to 225 L/min (20 to 60 gpm). Mechanical efficiencies may range from 50% to 90%, depending on the size and condition of the pump.

Rotary pumps, another type of positive-displacement pump, are popular for low-pressure sprayers, the most common types being roller pumps (Figure 10.24a). Roller pumps have a slotted rotor that rotates in an eccentric housing. Rollers in each slot seal the space between the rotor and the wall of the case. The rollers are held against the case by centrifugal force during pump operation. As the rollers go past the inlet the space expands creating low pressure and causing the liquid to be drawn in toward the housing. The liquid trapped between the rollers is moved towards the outlet as the rotor turns. Now the cavity between the rollers contracts, expelling the liquid out through the outlet port. Pump output is determined by the length and diameter of the housing, its eccentricity, and the speed of rotation.

Teflon is a common material for the rollers, although rubber, steel, and carbon are also used. Rotary pumps of are compact and relatively inexpensive, and can be operated at speeds suitable for direct connection to the tractor PTO. Although they are classed as positive-displacement pumps, leakage past the rollers causes a moderate decrease in flow as the pressure is increased. Normal output of roller pumps ranges from 19 to 114 L/min (5 to 30 gpm) and maximum pressures range from 1 to 3 MPa (150 to 300 psi). However, pressures above 690 kPa (100 psi) are not generally recommended for rotary pumps when pumping non-lubricating liquids. Roller pumps wear rather rapidly under abrasive conditions, but the rollers can be replaced economically.

Diaphragm pumps are another type of positive-displacement pump. They are becoming more widely used and are available with flow rates up to 19 to 23 L/min (5to 6



(c)

Figure 10.24 – (a) A typical roller pump, (b) a typical centrifugal pump, and (c) performance curves of roller and centrifugal pumps (reprinted from Bode and Butler, 1981).

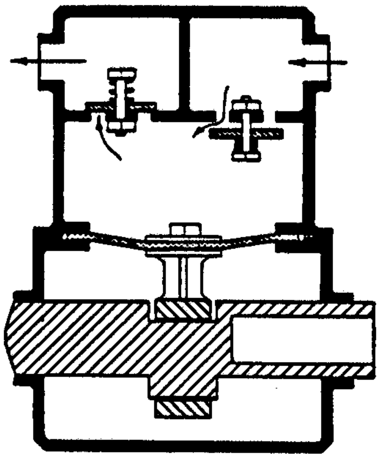


Figure 10.25 – A positive displacement diaphragm pump. (Reproduced by permission of Deere and Co. © 1991. All rights reserved.)

gpm) and pressures up to 3.4 MPa (500 psi). Since the valves and the diaphragm are the only moving parts in contact with the spray material, these pumps can readily handle abrasive materials (Figure 10.25).

Centrifugal pumps. *Centrifugal pumps* (Figure 10.24b) do not create flow by mechanically displacing a volume, as do positive-displacement pumps. Instead, they depend upon centrifugal force for their pumping action. They are essentially high-speed (3000 to 4500 rev/min), high-volume (70to 130 gpm) devices not suitable for high-pressure applications because the pump output drops off rapidly when the outlet pressure is above 206 to 275 kPa (30 to 40 psi). The pressure or head developed by a given centrifugal pump at a particular speed is a function of the discharge rate, as indicated by the typical performance curves in Figure 10.24c. Note that the peak efficiency, which occurs at a relatively high flow rate, is well above 70% for this particular unit, whereas efficiencies at small flows are low.

For a given centrifugal pump and a given point on the efficiency curve, the discharge rate varies directly with the speed, the head varies as the square of the speed, and the power varies as the cube of the speed. If two or more stages are connected in series, the head and power at a given discharge rate are increased in proportion to the number of stages. Thus, multi-staging provides increased pressures without increasing the capacity range.

Centrifugal pumps are popular for certain types and sizes of sprayers because of their simplicity and their ability to handle abrasive materials satisfactorily. They are well suited to equipment such as air-blast sprayers and aircraft sprayers, for which high flow rates are needed and the required pressures are relatively low, and are used on many low-pressure field sprayers. The high capacities are advantageous for hydraulic agitation and for tank-filling arrangements. Speeds in these applications are generally in the range between 1000 and 4000 rev/min, depending upon the pressure required and the diameter of the impeller.

Since centrifugal pumps do not have positive displacement, they are not self-priming and do not require pressure relief valves for mechanical protection. Priming is usually accomplished by mounting the pump below the minimum liquid level of the tank or providing a built-in reservoir on the pump that always retains sufficient liquid for automatic priming.

Power requirements. Power requirements of pumps are determined by flow rate, operating pressure, and mechanical efficiency. The mechanical efficiency used for estimating the power requirements is 50% to 60%. The pump input power can be calculated using the following formula:

$$P = \frac{Qp}{60{,}000\eta_m} \tag{10.1}$$

where P = power, kW

Q = flow rate, L/min

p = pressure, kPa

η_m = mechanical efficiency, decimal

10.2.3.2 Agitation

Many spray materials are suspensions of insoluble powders or are emulsions. Consequently, most sprayers are equipped with agitating systems, either mechanical or hydraulic.

Mechanical agitation is commonly accomplished by flat blades or propellers on a shaft running lengthwise in the tank near the bottom and rotating at a speed of 100 to 200 rev/min (Figure 10.26). The following relations apply to round-bottom tanks with flat, I-shaped paddles sweeping close to the bottom of the tank. They are based on results originally reported by French (1942) as cited in Kepner (1978).

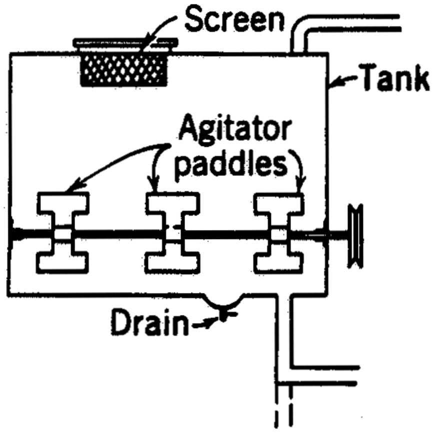


Figure 10.26 – Mechanical agitation (reprinted from Kepner et al., 1978).

$$s_m = 5.39A^{0.422}R^{-0.531}F_e^{0.293} \tag{10.2}$$

$$P_s = 3.26\times10^{-11}R^{0.582}s_m{}^{3.41}L \tag{10.3}$$

where s_m = minimum peripheral speed of paddles, m/min
A = depth of liquid above agitator shaft center line, mm
R = total combined width of all paddles divided by tank length
F_e = agitation factor indicating relative difficulty of agitating a given oil-water emulsion, either hydraulically or mechanically
P_s = shaft input power at any peripheral speed, s kW
L = length of tank, mm

Values of F_e for various oil-in-water emulsions are shown in Table 10.1. These were established during tests with hydraulic agitation but are assumed to apply reasonably well for mechanical agitation. French's tests were conducted with an emulsion containing 1% to 2% oil. No data are available to indicate mechanical agitation requirements for suspensions of wettable powders.

Paddle tip speeds in excess of about 150 m/min may cause significant foaming of some mixtures. For mechanical agitation of emulsions in flat-bottom tanks with rounded corners, the minimum tip speed from Equation 10.2 must be multiplied by the factor 1.11. This increase in minimum speed causes the minimum power requirement to be approximately doubled (Equation 10.3).

For *hydraulic agitation*, a portion of the pump's output is discharged into the spray tank through a series of jet nozzles or orifices located in a pipe along the bottom of the tank. The energy and turbulence from the jets provide the mixing action. Figure 10.27a shows different hydraulic agitator nozzles. In tests with various sizes of cylindrical tanks, Yates and Akesson (1963) found that best results were obtained when the jet nozzles were mounted as shown in Figure 10.27b. The location shown for wettable powders was satisfactory for an emulsion containing 40% oil and 60% water only when a suitable emulsifier was included in the formulation. Nozzle spacings from 75 to 710 mm were satisfactory for oil-water emulsions but not to exceed 305 mm for wettable powders.

Table 10.1. Values of agitation factors (F_e) for oil-in-water emulsions (Kepner et al., 1978).

Oil, %	Water, %	Emulsifier, %	Jet Position (Figure 10.27b)	Agitation Factor, F_e
60	40	0	emulsion	0.83
50	50	0	emulsion	1.00
40	60	0	emulsion	1.00
10	90	0	emulsion	0.89
1 – 2	99 – 98	0	emulsion	0.50
40	59.9	0.1	emulsion	0.50
40	59.9	0.1	wettable powders	0.68

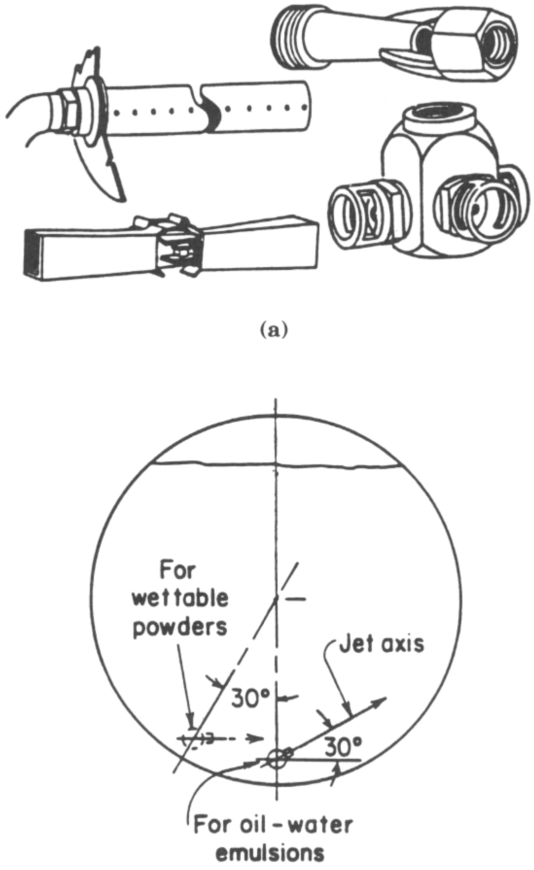
The minimum total recirculation rates for hydraulic agitation in a cylindrical or round-bottom tank, based on complete mixing of a full tank of material in 60 s, were found to be as follows:

For oil-water emulsions,

$$Q_m = 3830 \frac{VF_e}{p^{0.56}} \tag{10.4}$$

For wettable powders,

$$Q_m = 1380 \frac{VF_e}{p^{0.3}} \tag{10.5}$$



(a)

(b)

Figure 10.27 – (a) Various types of nozzles for hydraulic agitation (Bode and Butler 1981), and (b) locations of nozzles in the tank for agitation (reprinted from Kepner et al., 1978).

where Q_m = minimum total recirculation rate, L/min
V = tank volume, m^3
p = pressure at the agitation jet nozzle, kPa (ordinarily this will be essentially the same as the spray nozzle pressure)

The value of F_e was arbitrarily taken as 1.00 for a mixture of 120 g wettable sulfur per liter of water (1 lb/gal), since this is a difficult material to keep in suspension. Values of F_e for concentrations of 60, 12, and 6 g/L (0.5, 0.1, and 0.05 lb/gal) were found to be 0.87, 0.43, and 0.27, respectively. Table 10.1 indicates that adding an emulsifier to an oil-water mixture reduces the agitation requirements and also shows that F_e is greater when the jets are in the wettable powder optimum position (Figure 10.27b) instead of the emulsion position.

From basic hydraulic relations, the hydraulic useful power output required for any recirculation rate and pressure is:

$$P_h = \frac{Q_m p}{60{,}000} \tag{10.6}$$

where P_h = hydraulic power, kW
Q_m = total recirculation rate, L/min

The principal advantage of hydraulic agitation is its simplicity as compared with the mechanism and drive required for mechanical agitation. With hydraulic agitation, however, the spray pump must have additional capacity and the power requirements will be considerably greater than that for mechanical agitation, especially at high pressures. For high-pressure sprayers, mechanical agitation is definitely the more economical system.

Example 10.1

Determine the power requirements of a boom-type orchard sprayer if the spray gun pressure is 1.375 MPa and the flow rate is 15 L/min. The hose has an inside diameter of 2.54 cm, and it is 50 m long. The volume of the tank is 375 L and contains wettable powder. It is also recommended that a 20% over-capacity of flow should be designed to compensate for normal pump wear. The mechanical efficiency of the pump ranges from 50% to 60%. Assume the viscosity of the chemical is the same as that of water at 21° C or 0.98 MPa·s.

Solution

First we determine the pressure loss in the hose. Determine the flow regime by calculating the value of the Reynolds number as follows:

$$N_{Re} = \frac{4C\rho Q}{4\mu\, d} = \frac{4(16.67)1000(15)1.2}{\pi(0.98)25.4} = 15{,}348$$

Note that Q = 15 × 1.2 to account for 20% over-capacity as desired in the problem statement. The flow is fully developed turbulent flow since the Reynolds number is above 4000. To calculate the pressure drop, we use Equation 5.19:

$$\frac{\Delta p}{L} = \frac{0.0333\mu^{0.25}\rho^{0.75}Q^{1.75}}{d^{4.25}}$$

$$= \frac{0.0333(0.98)^{0.25}(1000)^{0.75}(15\times1.2)^{1.75}}{(25.4)^{4.25}}$$

$$= 0.922 \quad \text{kPa/m}$$

and $\Delta p = 0.992(50) = 49.59$ kPa. Thus, the total pressure required at the pump is:

$$p = 1375 + 49.59 = 1424.59 \text{ kPa}$$

Now, determine the flow rate required for hydraulic agitation using the following equation for wettable powder:

$$Q_m = 1380\frac{VF_e}{p^{0.35}} = \frac{1380(0.375)0.68}{(1425)^{0.35}} = 27.7 \quad \text{L/min}$$

Thus, the total flow that the pump must generate is:

$$Q = 15(1.2) + 27.2 = 45.2 \text{ L/min}$$

Pump output power is, from Equation 10.14:

$$P = 1.667 \times 10^{-5}\ QP = 1.667 \times 10^{-5}\ (45.2)(1424.59) = 1.07 \text{ kW}$$

Considering the lowest efficiency of 50%, the input power is:

$$P_{input} = 1.07/0.5 = 2.14 \text{ kW}$$

10.2.3.3 Atomization

The main objective of atomization is to increase the surface area of the liquid by breaking it into many small droplets for effective coverage of plant and soil surfaces. During atomization, energy is imparted to the liquid to break it into small droplets by overcoming surface tension, viscosity, and inertia.

Types of atomizers. Based on the form of energy applied to produce atomization, the atomizers may be categorized as *pressure, rotary,* or *pneumatic* atomizers. Pressure atomizers are the most common type used in agriculture; use of the pneumatic kind is virtually non-existent.

In *pressure atomizers,* pressure energy is used to breakup a liquid jet. Pressure atomizers (but not rotary atomizers), often referred to as *nozzles* (Figure 10.28), produce several different spray patterns (Figure 10.29), described below.

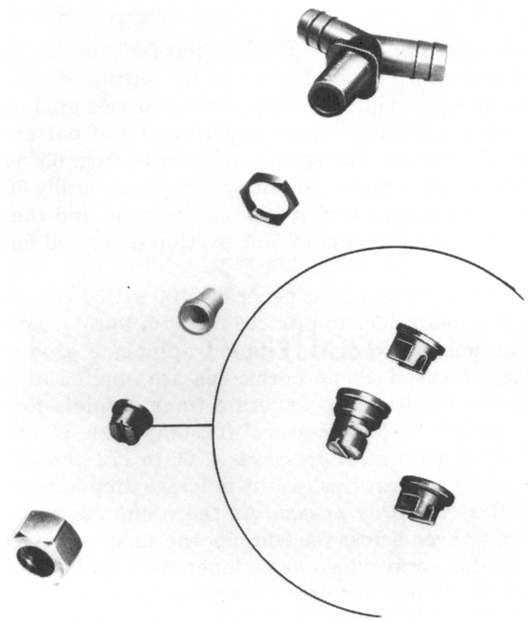


Figure 10.28 – A typical nozzle assembly. (Reproduced by permission of Deere and Co. © 1991. All rights reserved.)

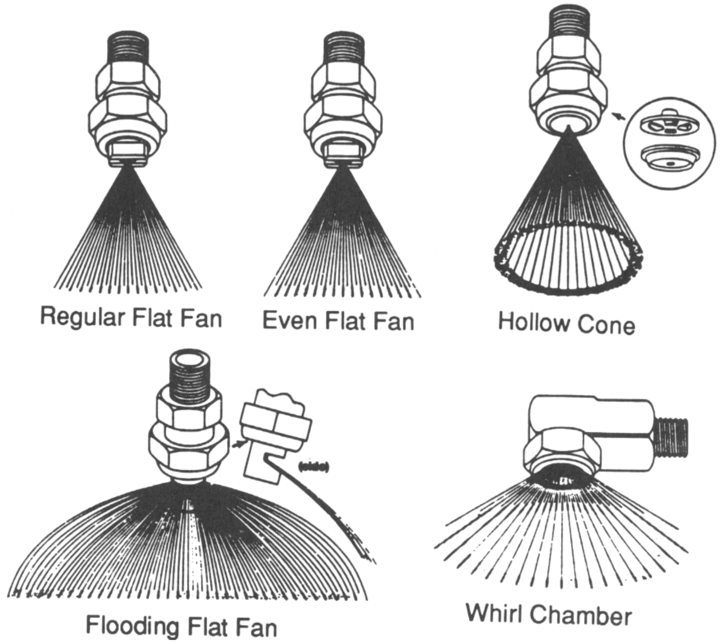


Figure 10.29 – Various types of spray nozzles and spray patterns (reprinted from Bode and Butler, 1981).

Regular flat-fan nozzles are used for most solid applications of herbicides and for certain pesticides when it is not necessary to penetrate foliage. These nozzles produce a tapered-edge flat-fan spray that requires overlapping of pattern to obtain uniform coverage. The spray angle varies from 65° to 110° with 80° being the most common. Nozzle spacing is generally 50 cm on the boom. The boom height varies with spray angle and the amount of overlap desired. A minimum of 50% overlap is needed for uniform coverage.

The operating pressure is generally 100 to 200 kPa (15 to 30 psi) when applying herbicides to produce medium to coarse droplets that are not susceptible to drift. Finer droplets are produced as the pressure is increased. Some herbicides are applied at pressure of 275 to 413 (40 to 60 psi) to generate finer droplets for maximum coverage. The LP or “low pressure” flat-fan nozzle develops normal pattern at pressures of 69 to 172 kPa (10 to 25 psi). Operating at lower pressures results in larger drops and less drift.

Even flat-fan spray nozzles provide a spray density that is more even across the width of the spray, as compared to the standard flat-fan spray with its tapered spray distribution. Since overlapping would produce a very uneven spray pattern, these nozzles are only for band application over or inbetween rows. The band width is determined by adjusting the boom height. The common spray angles are 80° and 95° and the operating pressures range from 100 to 200 kPa (15 to 30 psi).

Flooding flat-fan nozzles produce a wider spray pattern than the other flat-fan nozzles. They are most suited for broadcast applications where uniform surface application is critical. Uniform spray application is obtained by 100% overlap of individual spray patterns. These nozzles produce large droplets and reduce drift, when operated at 55 to 170 kPa (8 to 25 psi) pressure. Pressure changes affect the uniformity of spray pattern more with flooding flat-fan nozzles than with regular flat-fan nozzles.

Hollow-cone spray nozzles (both disk and core types) utilize a two-piece, disk-core, hollow-cone spray tip. The core gives the fluid a swirling action before it is metered through the orifice disk, resulting in a circular, hollow-cone, spray pattern. These nozzles are most suited for directed spray in row-crop applications when drift is not a concern, as these nozzles are operated at 275 to 550 kPa (40 to 80 psi) pressures. Since the droplets are small, these nozzles are most suited for contact herbicides, insecticides, and fungicides where full coverage of plant foliage is essential.

Whirl-chamber hollow-cone nozzles have a whirl-chamber above a conical outlet that produces a hollow-cone pattern of cone angles up to 130°. These nozzles are best suited for broadcast surface applications of herbicides. For best results the nozzle is tilted towards the rear at a 45° angle. Since the droplets tend to be larger, these nozzles are most suited for systemic herbicides and where drift may be a problem. The operating pressure ranges from 35 to 138 kPa (5 to 20 psi).

In *rotary atomizers*, as opposed to the various pressure nozzles listed above, the energy to produce droplets comes from a rotating wheel, disk, or cup. As the speed increases, smaller droplets are produced. Rotary atomizers (Figure 10.30) are not as common in agricultural applications as are pressure nozzles. Rotary atomizers are also called *controlled droplet atomizers* (CDA) for their ability to produce droplets that are more uniform in size compared to other atomizers.

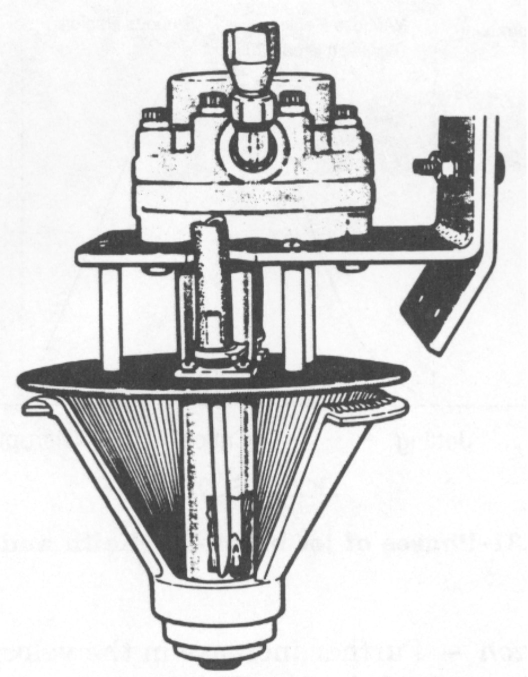


Figure 10.30 – A rotary or controlled droplet atomizer (courtesy of Farm Fans, Inc.).

Theory of pressure atomization. Atomization is a very complex process and depends highly upon the type of atomizer. To get a better understanding of the process we will discuss breakup of *liquid jets*, *liquid sheets*, and *liquid droplets*.

Liquid jet breakup. As the liquid flow rate is increased through a horizontal nozzle, it goes through the following four phases based on the Reynolds number (Figure 10.31). Think of N_{Re} as an indicator of flow rate. With everything else being the same, as flow rate increases, N_{Re} also increases. There are generally two flow regimes: laminar and turbulent. Two very different flow behaviors exist in these regimes.

1. *Drop formation.* At low flow rates drops form individually at the tip of the nozzle and grow in size until the weight overcomes the interfacial tension and the drop is released (Figure 10.32).

2. *Varicose region*. As the jet velocity is increased, symmetrical bulges and contractions appear and the jet lengthens. The drops become smaller and less uniform.

3. *Sinuous region*. Further increase in the velocity results in the transverse oscillations of the jet. The jet waves irregularly in an S-curve fashion. The jet becomes shorter and the drops become larger.

4. *Atomization*. Finally, the jet breaks down into small droplets, usually within a distance of 15 times jet diameter of the orifice. The breakup is highly chaotic. The ligaments shed at the crest as the jet oscillates further break down into droplets. This occurs when a simple orifice is employed for atomization.

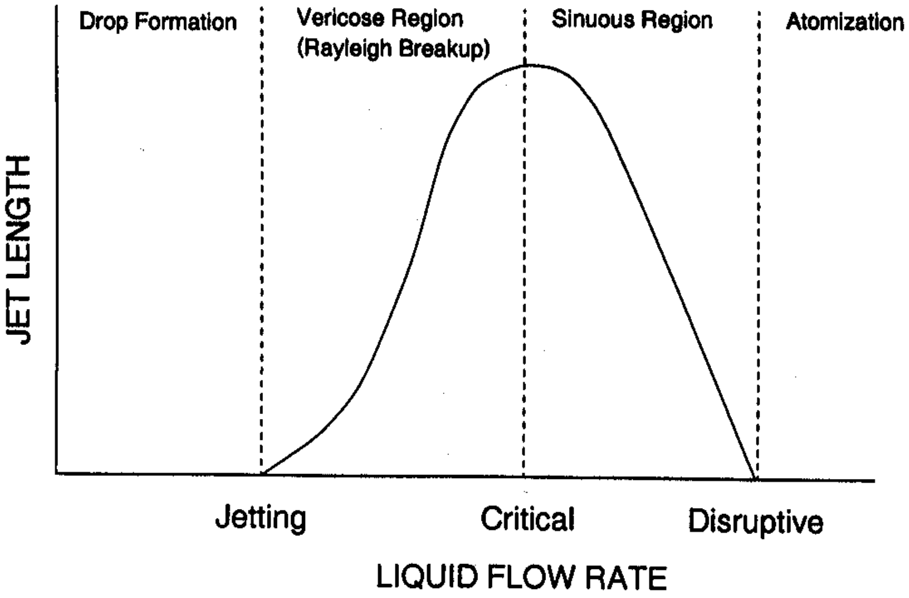


Figure 10.31 – Phases of jet breakup (Keith and Hixon, 1955).

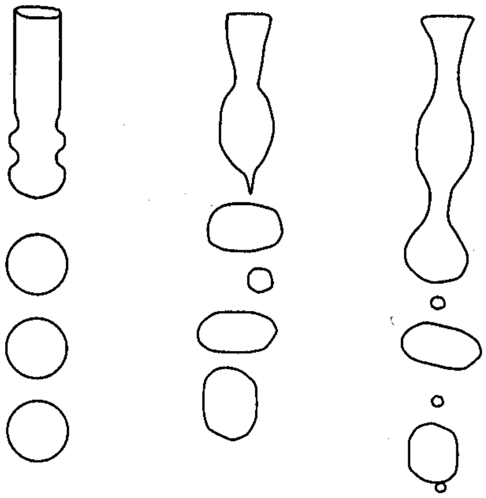


Figure 10.32 – Idealized and actual jet breakup (Marshall, 1954).

The jet is moving from the sinuous region to the atomization region when the following equation is true:

$$\left(\frac{d_j v_j \rho_l}{\mu_l}\right) \geq 280\left[\frac{\mu_l}{(\sigma\rho_l d_j)^{0.5}}\right]^{-0.82} \tag{10.7}$$

where d_j = jet diameter, m
v_j = jet velocity, m/s
ρ_l = liquid density, kJ/m^3
μ_l = liquid viscosity, Pa·s
σ = surface tension (N/m)

The jet velocity can be computed as follows once flow through the nozzle is known:

$$v_j = C_v\left(2\frac{\Delta p}{\rho_l}\right)^n \tag{10.8}$$

where C_v = velocity coefficient, dimensionless
Δp = total pressure drop, Pa
$n = 0.5$ for turbulent flow

The discharge coefficient represents the ratio of the actual liquid discharge rate to that theoretically possible. The volumetric flow rate is determined by:

$$Q = v_j C_A A \tag{10.9}$$

where C_A = area coefficient, dimensionless
A = nozzle orifice area, m^2

C_A takes into account the vena contracta effects. Combining Equations 10.8 and 10.9 we obtain:

$$Q = C_v\left(\frac{2\Delta p}{\rho_l}\right)^{0.5} C_A A \tag{10.10}$$

Now, if we let discharge coefficient $C_D = C_v\, C_A$, the above equation becomes:

$$Q = C_D A\left(\frac{2\Delta p}{\rho_l}\right)^{0.5} \tag{10.11}$$

The average jet velocity may be computed from the above equation as follows:

$$v_j = \frac{Q}{C_D A} \tag{10.12}$$

The discharge coefficient (C_D) varies depending upon the size of the orifice and the nozzle design. For a given nozzle, if we plot flow rate against the square root of the pressure drop, the slope of the line will be $C_D\ A\ \sqrt{2/\rho_l}$ from which the discharge coefficient (C_D) may be computed.

Example 10.2

A spray nozzle manufacturer has provided the following pressure-flow rate data for a hollow-cone nozzle spraying water.

Nozzle flow rates at various pressures for an orifice diameter of 2.39 mm.

Pressure, kPa	207	276	345	414	552	689	862	1034	1379	2068
Flow, L/min	1.17	1.63	1.82	2.00	2.31	2.57	2.95	3.14	3.71	4.54

For the above nozzle determine the flow required to produce atomization phase of a jet of water issuing from the nozzle.

Solution

Equation 10.7 is to be used to determine the jet velocity required to produce atomization. This equation can be rewritten as:

$$v_j \geq 280 \frac{\sigma^{0.42} \mu_l^{0.18}}{\rho_l^{0.59} d_j^{0.59}}$$

For water, $\sigma = 0.0728\ \mathrm{N/m}$
$\mu_l = 1\ \mathrm{mPa \cdot s}$
$\rho_l = 1000\ \mathrm{kg/m^3}$
$d_j = 2.39\ \mathrm{mm}$

Using the above values, $v_j > 16.06\ \mathrm{m/s}$.

Equation 10.12 may be used to calculate the flow corresponding to the minimum jet velocity of 16.06 m/s as:

$$Q = C_D\, A\, v_j$$

However, the discharge coefficient (C_D) is to be determined from the data given by the manufacturer. If we plot the nozzle flow against the square root of the nozzle pressure as shown on the next page, we find the slope as:

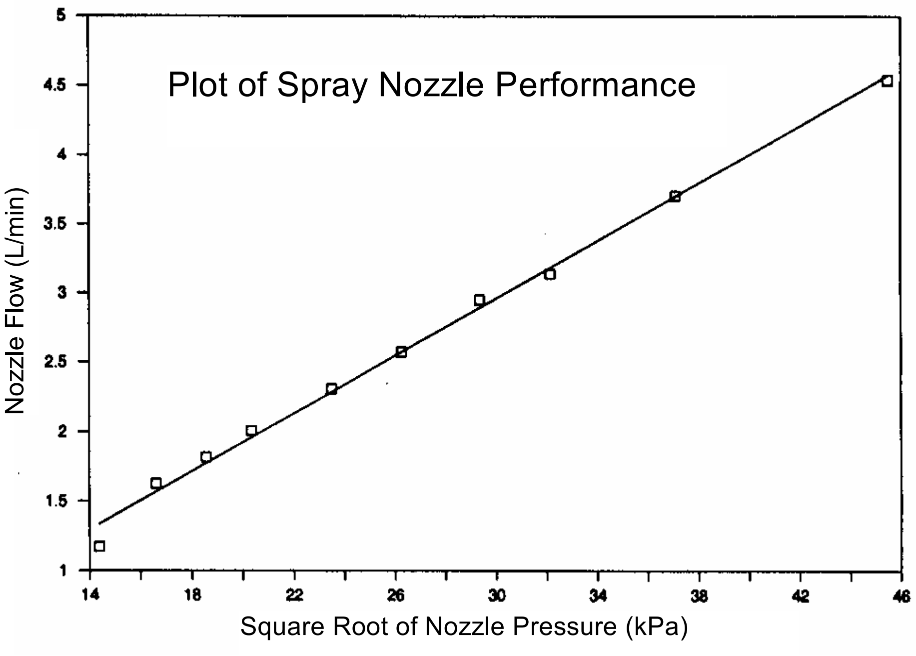
$$0.104 \frac{\mathrm{L/min}}{\mathrm{kPa}} \qquad \text{or} \qquad 10^{-6} \frac{\mathrm{m^3/s}}{\sqrt{\mathrm{kPa}}}$$

Using Equation 10.11 we get:

$$\frac{C_D A \sqrt{2}}{\sqrt{\rho_l}} = 5.48 \times 10^{-8} \frac{\mathrm{m^3/s}}{\sqrt{\mathrm{Pa}}} \qquad \text{(note conversion from kPa to Pa)}$$

or

$$C_D = \frac{\sqrt{\rho_l}}{A\sqrt{2}} \times 1.735 \times 10^{-6}$$



Substituting the values of ρ_l and A, C_D is found to be 0.274. Note that this value is considerably less than 0.611 normally used for turbulent orifice flow. This is due to the inserts and screens used in a working nozzle.

Once C_D is known, the flow is calculated as:

$$Q = 0.274\left[\frac{\pi}{4}(2.39\times10^{-3})^2\right]\times16.06$$

$$= 19.7\times10^{-6}\,\mathrm{m}^3/\mathrm{s}$$

$$= 1.18\ \ \mathrm{L/min}$$

It should be noted that this value corresponds to a pressure drop of 207 kPa. If the nozzle is operated at pressure less than 207 kPa, complete atomization will not occur. It should also be noted that this value corresponds to the minimum value of pressure given by the manufacturer. If lesser flow is desired, a smaller orifice should be used.

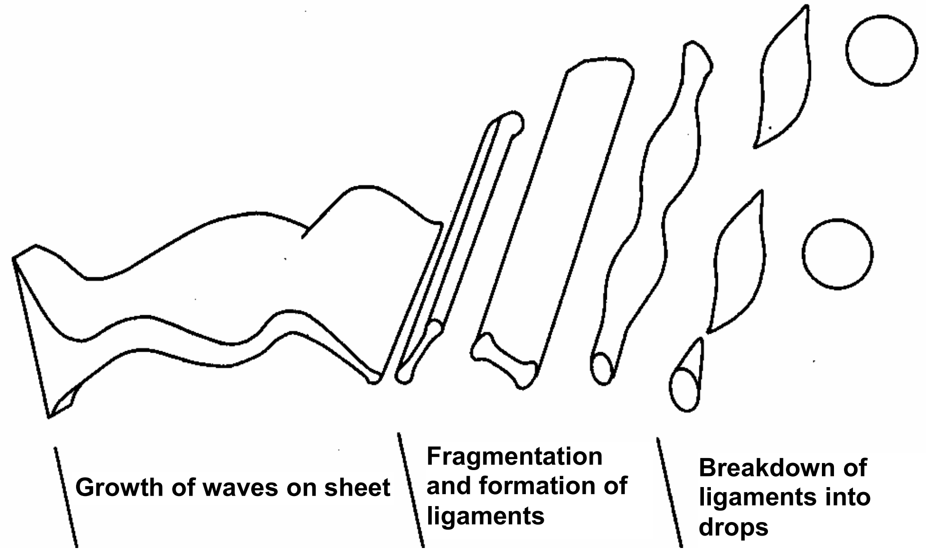


Figure 10.33 – Breakup of a liquid sheet (after Dombrowski and Johns, 1963).

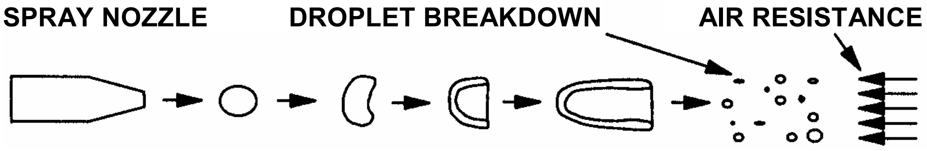


Figure 10.34 – Breakup of a droplet.

Liquid sheet breakup. When the liquid is pumped through a pressure nozzle, either a flat-fan (fanjet) nozzle or a whirl-chamber (swirl) nozzle, a sheet of liquid is formed. The liquid sheet breaks up into droplets of many sizes. The mechanism of sheet breakup is complex and depends upon many factors. However, four main mechanisms have been observed (Figure 10.33):

1. *Rim disintegration.* The free edge of the sheet contract into a cylinder, that then breaks from the surface as large drops followed by their liquid fingers.
2. *Sheet perforations.* Perforations appear in the sheet that expand under the influence of surface tension until ligaments remain.
3. *Unstable waves* are formed in the sheet at a right angle to the direction of flow of liquid. The amplitude increases until the sheet breaks up.
4. *Thick sheet breakup.* The crests of sheet are shed as ligaments.

Liquid droplet breakup. Droplets further break down in an air stream if the aerodynamic forces exceed the surface tension force. This may occur in air carrier sprayers. A sequence of droplet breakup is shown in Figure 10.34.

Droplet size and size distribution. When liquid is atomized, droplets of various sizes are formed. The spray droplets are classified by their diameters, typically measured in microns (μ).[1] The performance and effectiveness of an atomizer depends upon the droplet size and size distribution. Table 10.2 shows some of the characteristics of various size droplets. The area covered and the volume of liquid in individual droplets is important in achieving effective and efficient application. Smaller droplets of the same volume provide more coverage. For example, one 200 μ droplet when broken into 64 droplets of 50 μ diameter will cover four times more area than the 200 μ droplet. The droplet distribution is also important from the point of view of spray drift. As seen in Table 10.5 the smaller the droplet size the longer it takes for it to settle and the higher the probability of drift. Note also that droplets evaporate in flight, becoming smaller and thereby increasing the chances of drift.

Droplet size distribution can be represented by a plot of the number of particles of a given diameter, as in Figure 10.35. This kind of plot is called a histogram. A smooth curve through the center points of the maxima of each size class gives the distribution curve. This curve represented by a function, f(x), is commonly called a distribution function. If the distribution function is known explicitly, then only a few parameters (e.g., mean diameter and standard deviation) are needed to define a given distribution. Minimum and maximum size are additional parameters, often associated with a distribution. Sometimes, the surface area or the volume of a droplet is more relevant in certain applications rather than the diameter. If this is used as the ordinate then the curve in Figure 10.35 would skew to the right because of the weighting effect of the surface area or volume associated with a droplet diameter.

Table 10.2. Spray droplet size and its effect on coverage for a 10 L/ha application rate (Bode and Butler, 1981).

Droplet diameter, μ	Type of droplet	Area relative to a 10 μ droplet	Volume relative to a 10 μ droplet	No. of droplets per cm^2	Coverage relative to 1000 μ droplet
5	Dry fog	0.25	0.125	1,524,647	200
10	Dry fog	1	1	190,581	100
20	Wet fog	4	8	23,822	50
50	Wet fog	25	125	1,525	20
100	Misty rain	100	1000	191	10
150	Misty rain	225	3375	56	6.7
200	Light rain	400	8000	24	5
500	Light rain	2500	125,000	1.5	2
1000	Heavy rain	10,000	1,000,000	0.2	1

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[1] Microns are also called micrometers and may be abbreviated μm. One micron is one millionth of a meter or 1/25,400 of an inch. A person with normal eyesight can see 100 μmwithout any magnification.

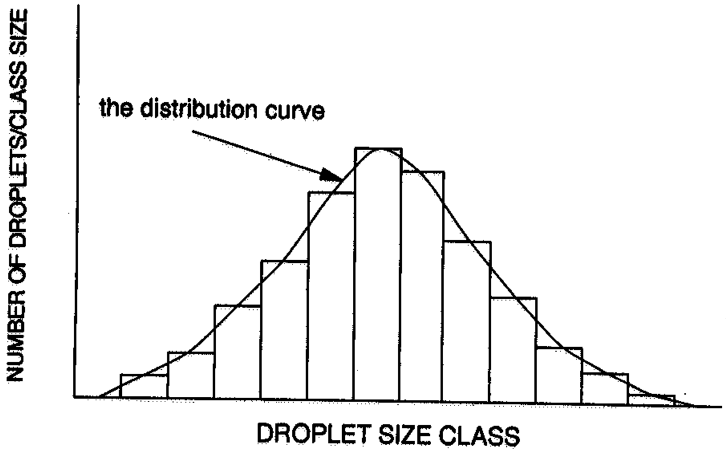


Figure 10.35 – A histogram of droplet sizes and associated frequency.

A more convenient method of representing a particle size distribution is to plot the cumulative fraction of the total number smaller than a given size against that given size. This plot is called a cumulative frequency plot and is shown in Figure 10.36. A more convenient way is to plot the data on a probability paper is shown in Figure 10.37. The droplet diameter is plotted on the ordinate (y-axis) and the abscissa is the cumulative percentage of droplet number, length, surface area, or volume. In pesticide application the cumulative number and cumulative volume are the most commonly used plot. The slope of the curve is an indication of the uniformity of the droplet size distribution.

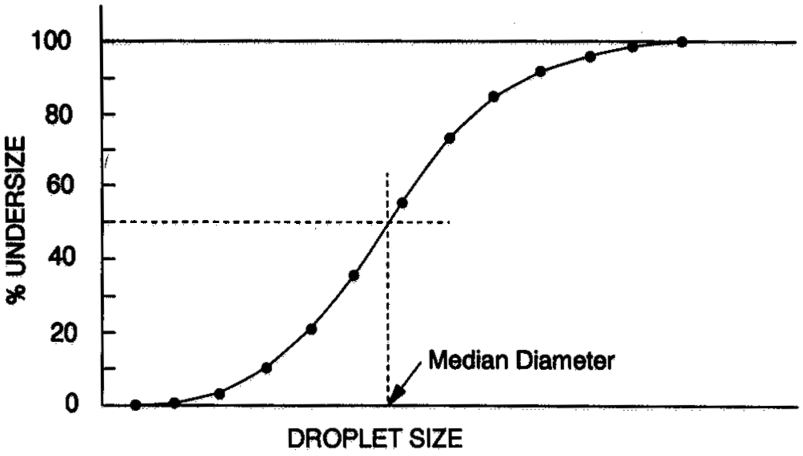


Figure 10.36 – A cumulative frequency plot.

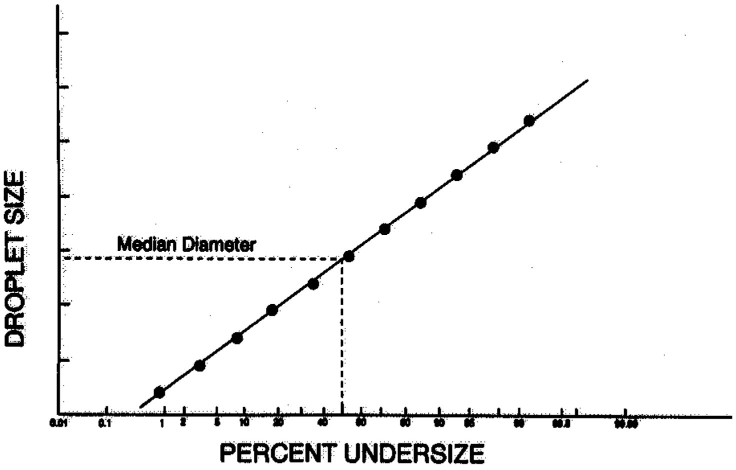


Figure 10.37 – A cumulative frequency plot on a normal probability paper.

The *median drop diameter* divides the spray into two equal parts by number, length, surface area, or volume. Number and volume median diameters are determined from the cumulative probability plots such as shown in Figure 10.38. A uniform method has been proposed to express the median diameters as D_{xf}. The subscript, x, can be V for volume, A for area, L for length, or N for number, and the subscript, f, is the fraction on the cumulative distribution plot. Thus, $D_{v.5}$ = volume median diameter (VMD) indicates that 50% percent of liquid volume is in droplets smaller than this diameter and 50% in droplets larger than this diameter.

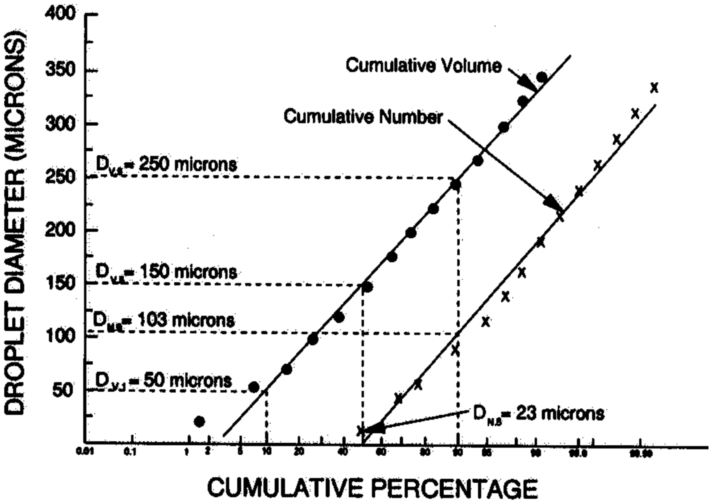


Figure 10.38 – Cumulative number and volume curves for a typical spray nozzle (after Bode and Butler, 1981).

Mean droplet diameters are weighted averages. Their names depend on the method used to compute the average. The following equation can be used to calculate the mean diameters:

$$\bar{D}_{pq}^{\,p-q} = \left(\frac{\sum_{i-1}^{n} N_i D_i^p}{\sum_{i=1}^{n} N_i D_i^q} \right)^{1/(p-q)} \tag{10.13}$$

where p,q = 1, 2, 3, or 4 and p > q

D_i = droplet diameter for the *i*th size class
N_i = number of droplets in the *i*th size class
i = number of the size class
n = total number of size classes

Various weighted averages may be computed based on the number of droplets in each class size. Commonly used means include: arithmetic mean ($\bar{D}_{10}$), surface mean ($\bar{D}_{20}$), volume mean ($\bar{D}_{30}$) and Sauter mean ($\bar{D}_{32}$). The arithmetic mean is computed by letting p = 1 and q = 0 in the above equation and it is the weighted average of all droplet diameters in the spray. Volume mean diameter (p = 3 and q = 0) is the diameter of the droplet whose volume times the number of droplets in the spray equals the total volume sprayed. Sauter mean diameter is calculated by equating p = 3 and q = 2 and it is an indicator of the volume to surface ratio of droplets in the spray. Similarly, the surface mean diameter, with p = 2 and q = 0, is the diameter of the droplet whose surface area times the number of droplets in the spray equals the total surface area of all droplets.

There is no general agreement as to which method of specifying droplet diameters is the best in agricultural chemical application. However, volume mean and Sauter mean diameters are most commonly used. Median diameters have a better physical significance in that they divide the droplet spectra equally based on the count, area, volume, etc.

Example 10.3

For the droplet size data given on the next page, determine the mean and median droplet diameters.

Class size range, μ	Number of droplets in each class size range
19 – 46	699
46 – 72	326
72 – 99	282
99 – 125	286
125 – 152	243
152 – 178	201
178 – 204	150
204 – 231	88
231 – 259	50
259 – 284	43
284 – 310	13
310 – 336	12
336 – 363	5
363 – 389	2
389 – 415	1

Solution

Mean droplet diameters are computed from the table below (Bode and Butler, 1981).

Size (diameter) class range, μ	Midpoint diameter, μ	No. in each size class, N	ND, μ	ND^2, μ^2	ND^3, μ^3
19 – 46	32	699	22,368	715,776	22,904,832
46 – 72	59	326	19,234	1,134,806	66,953,554
72 – 99	85	282	23,970	2,037,450	173,183,250
99 – 125	112	286	32,032	3,587,584	401,809,408
125 – 152	138	243	33,534	4,627,692	638,621,496
152 – 178	165	201	33,165	5,472,225	902,917,125
178 – 204	191	150	28,65	5,472,225	1,045,180,650
204 – 231	217	88	,19,096	4,143,832	899,211,544
231 – 259	245	50	12,250	3,001,250	735,306,250
259 – 284	272	43	11,696	3,181,312	865,316,864
284 – 310	297	13	3,861	1,145,717	340,574,949
310 – 336	323	12	3,876	1,251,948	404,379,204
336 – 363	349	5	1,745	609,005	212,542,745
363 – 389	376	2	752	282,752	106,314,752
389 – 415	402	1	402	161,604	64,964,808
	Totals	2401	246,631	36,826,178	6,880,181,431

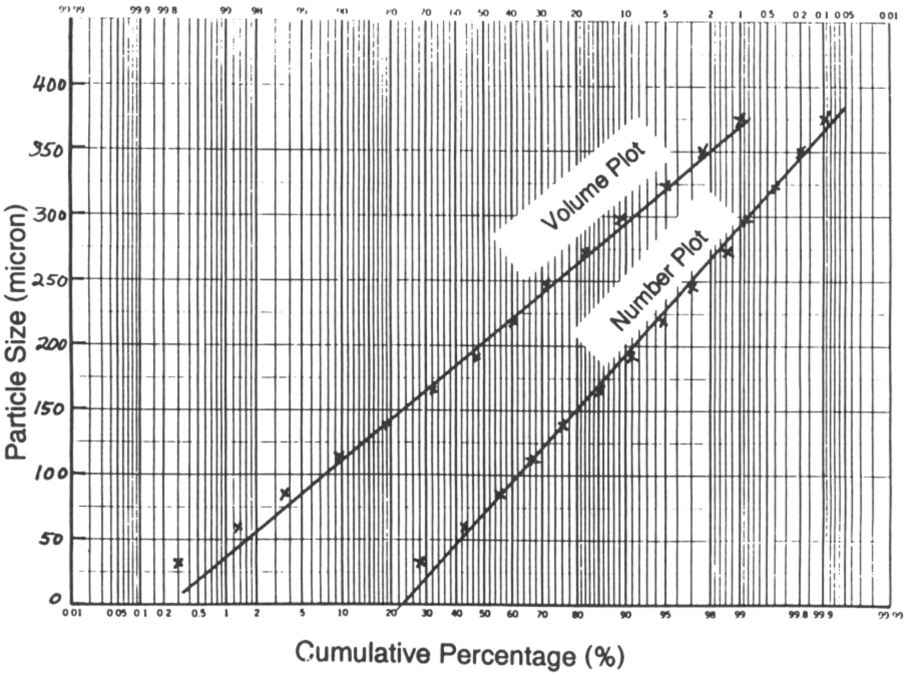
Mean droplet diameters are: $\bar{D}_{10} = 102.7\mu$ $\bar{D}_{30} = 142.0\mu$

$D_{20} = 123.8\mu$ $\bar{D}_{31} = 167.0\mu$

$\bar{D}_{21} = 149.3\mu$ $\bar{D}_{32} = 186.8\mu$

To determine median diameters, complete the table as shown below and then plot the data on a probability paper as shown. Mean diameters are determined from the plot.

Size class midpoint, μ	No. in each size class	No. in each size class, %	Cum. % by number	Vol. in each size class, %	Cum. % by volume
32	699	29.1	29.1	0.3	0.3
59	326	13.6	42.7	1.0	1.3
85	282	11.7	54.4	2.5	3.8
112	286	11.9	66.3	5.8	9.6
138	243	10.1	76.4	9.3	18.9
165	201	8.4	84.8	13.1	32.0
191	150	6.2	91.0	15.2	47.2
217	88	3.7	94.7	13.1	60.3
245	50	2.1	96.8	10.7	71.0
272	43	1.8	98.6	12.6	83.6
297	13	0.5	99.1	4.9	88.5
323	12	0.5	99.6	5.9	94.4
349	5	0.2	9.8	3.1	97.5
376	2	0.1	99.8	1.6	99.1
402	1		99.9	0.9	100
			100		
		$D_{N.1}$ = not applicable		$D_{V.1}$ = 50 μ	
		$D_{N.5}$ = 75 μ		$D_{V.5}$ = 195 μ	
		$D_{N.9}$ = 188 μ		$D_{V.9}$ = 300 μ	



10.3 PERFORMANCE EVALUATION

10.3.1 Uniformity of coverage of granular chemical application

The performance of a dry chemical applicator is measured by the uniformity of coverage and the calibration accuracy. The uniformity of coverage is based on the uniformity of metering and on the spreading or distribution. Field variables affect the uniformity and calibration accuracy. Bumpy and sloping fields result in undesirable performance. The material being applied also affects the performance. Free-flowing materials produce a more uniform application, as opposed to the materials that tend to form clumps and do not meter well.

A typical metering uniformity for 24 outlets across the width of the applicator is shown in Figure 10.39. The coefficient of variation (C.V.) was 9.5%. The C.V. is a measure of the scatter in a data set and it is computed by dividing the standard deviation by the sample mean. The higher the C.V., the greater the scatter in the data.

The uniformity of spreading is expressed in terms of application rate at a given location across the width of the applicator. The distribution and C.V. shown in Figure 10.40 is typical.

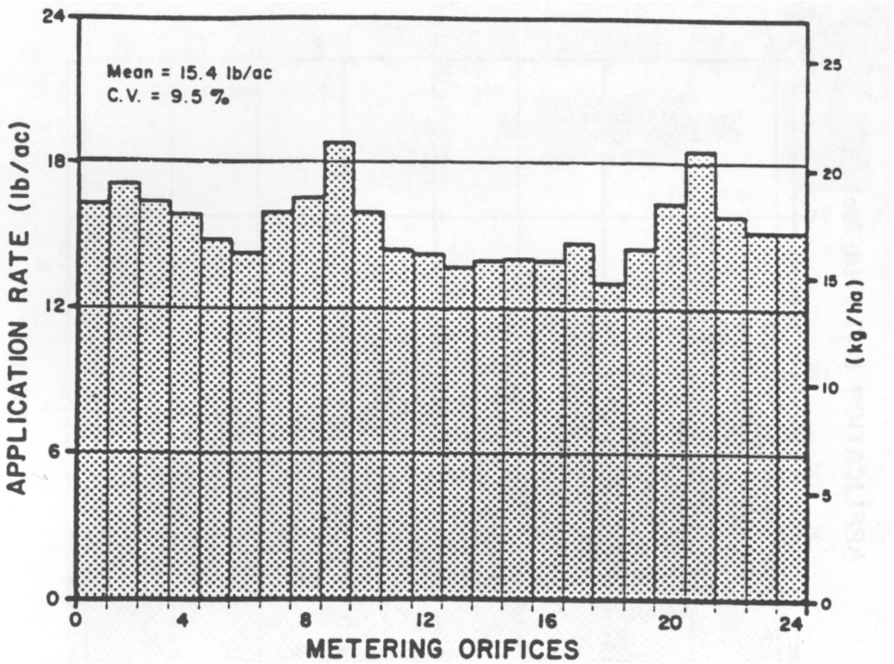


Figure 10.39 – Typical variation in delivery rates from individual outlets with the original set of hopper bottoms while applying Avadex BW at 17.3 kg/ha (15.4 lb/ac) and 8 km/h (5 mph) (courtesy of Prairie Agricultural Machinery Institute, Canada).

In addition to the lateral uniformity of application, longitudinal uniformity also affects the applicator performance. The longitudinal uniformity usually is in the form of cyclic variations that are caused by the design of the metering mechanisms. Figure 10.41 shows different lateral distribution patterns for centrifugal spreaders. The overall uniformity is based on the individual pattern and the amount of overlap for each swath.

The performance of rotary broadcast-type fertilizer distributors is affected by the speed of the spinning disk and the size of fertilizer granules, among other factors. Crowther (1958) conducted a study of these effects. A commercial fertilizer was used in the study with size distribution such that 92% of particles pass through sieve opening 3353 μ, 36% at 2411 μ and 4% at 1190 μ. Figure 10.41 shows that as the speed of the disk increased the particles were thrown farther, which was expected. However, distribution of the spread density across the width of the distributor was also affected. Figure 10.42 shows the segregation of the particles at 400 rev/min. There is some segregation of particles according to their size; however, it is not likely to affect the overall distribution pattern.

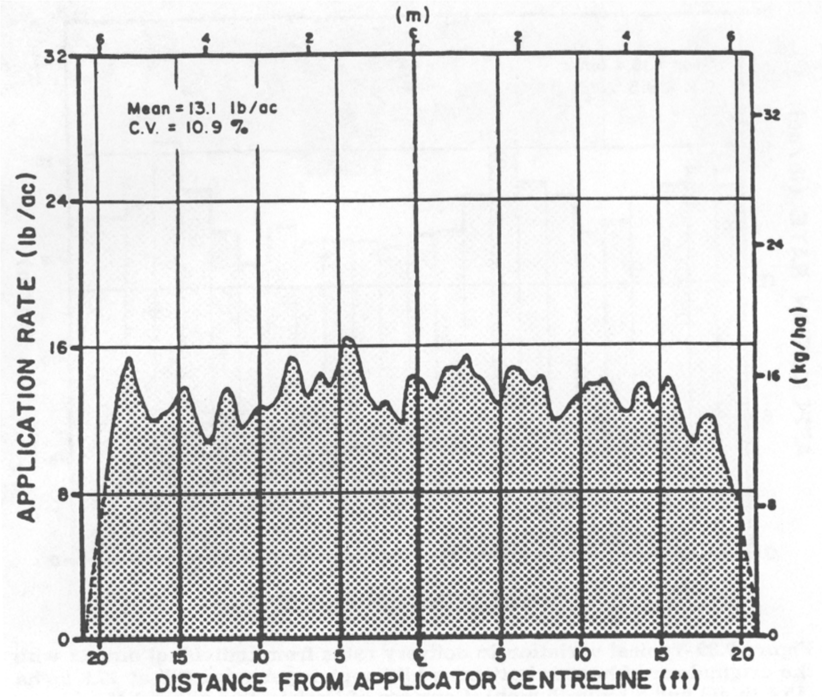


Figure 10.40 – Typical distribution pattern using the original hopper bottoms when applying 14.7 kg/ha (13.1 lb/ac) of Avadex BW at 8 km/h (5 mph) using 610 mm (24 in.) deflector spacing and a 610 mm (24 in.) deflector discharge height (courtesy of Prairie Agricultural Machinery Institute, Canada).

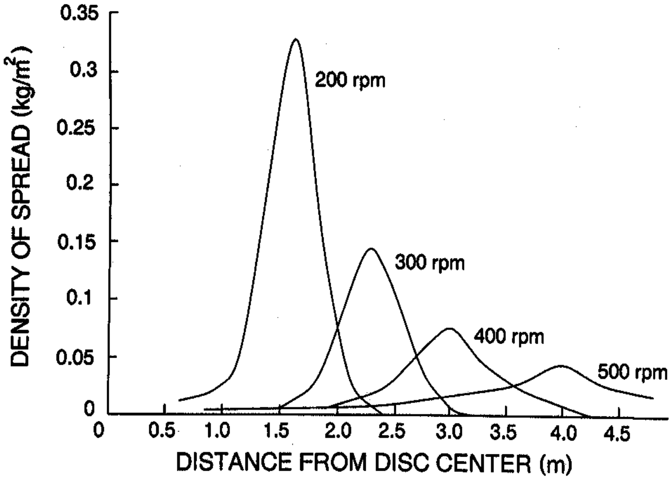


Figure 10.41 – The effect of disk speed on the distance the particles are thrown by the distributor (Crowther, 1958).

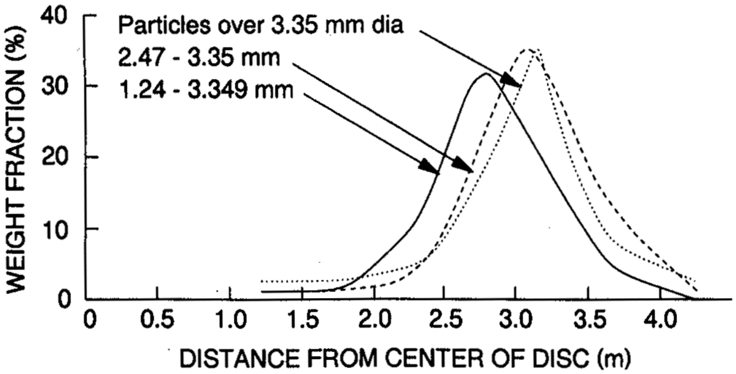


Figure 10.42 – Segregation of particles due to their size by the spinning disk (Crowther, 1958).

10.3.2 Calibration of fertilizer spreaders

10.3.2.1 Gravity spreaders

Calibration refers to the amount of chemical applied per unit area and is usually expressed as kilograms per hectare (kg/ha). The fertilizer (or other product) label indicates the recommended application rate. Sometimes the application rate is specified in terms of the amount of active ingredient to be applied per unit area since agricultural chemicals, particularly pesticides, are available in different formulations. In this case the product application rate can be computed using the following formula:

$$AR = \frac{AR_{ai}}{FR_{ai}} \tag{10.14}$$

where AR = product application rate, kg/ha

$AR_{a.i.}$ = application rate of the active ingredient in the formulation

$FR_{a.i.}$ = fraction of the active ingredient in the formulation

The rate of application is independent of the ground speed of the applicator as the metering rate is proportional to the rate of travel. This is accomplished by driving the metering mechanism by the ground wheel. Different fertilizers and pesticides require different application rates, so the applicator should be calibrated to the desired rate of application. The manufacturers of the applicators provide for the adjustment of the orifice to vary the application rate.

An applicator may be calibrated in the laboratory, although field calibration is recommended because ground roughness affects the rate. If the application rate is not correct, the applicator should be adjusted and the calibration should be performed again.

To calibrate in the field, fill the hopper with material and adjust the gage to the recommended setting. Pull the applicator forward until a steady stream is flowing from the tubes. Mark a distance at least 200 m. Remove the tubes and attach bags to collect the material. After traveling the marked distance at the desired speed, collect and weigh the material. The following formulas may be used to determine the application rate:

$$A = \frac{d\,w}{10{,}000} \tag{10.15}$$

$$AR = \frac{m}{A} \tag{10.16}$$

where A = treated area, ha

d = distance traveled, m

w = swath width, m

AR = application rate, L/ha

m = amount of material collected, kg

For laboratory calibration, the applicator is jacked up and the ground wheel is turned several times to simulate field travel. The granules are collected and weighed. The distance traveled in Equation 10.15 is then determined by:

$$d = \pi D_w N \tag{10.17}$$

where D_w is the ground wheel diameter (m) and N is the number of revolutions.

For banded applications, the rate of application in the band is the same as the recommended field application rate. Less total product is applied since the treated area is less than the total area. The following formula is used to compute the treated area in banded applications:

$$A_b = \frac{d_b A}{d_r} \tag{10.18}$$

where A_b = band treated area, ha

d_b = band width, m

d_r = row spacing, m

Table 10.3. Pan spacing for collecting samples to determine spread pattern.

Swath width (m)	Pan spacing, m, 9 pans	Pan spacing, m, 11 pans
9.144	1.143	1.066 on each side of center pan 0.991 between all other pans
10.668	1.321	1.066
12.192	1.524	1.219
13.716	1.727	1.372
15.240	1.905	1.524

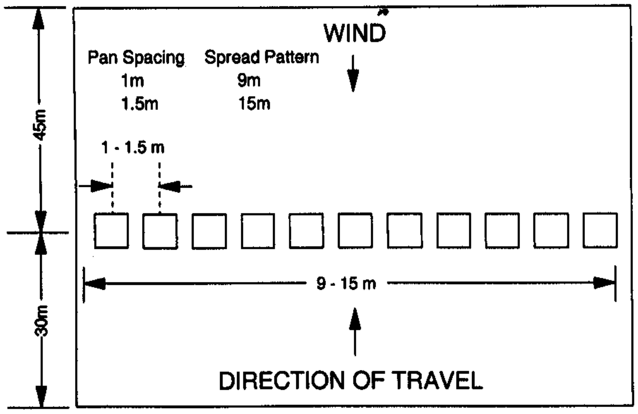


Figure 10.43 – Diagram showing the minimum requirements for a spread pattern test area.

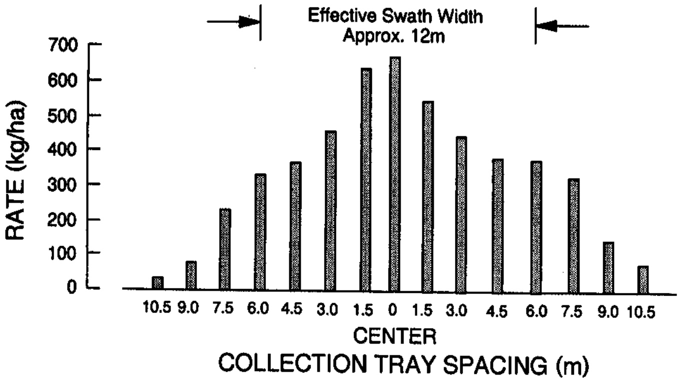


Figure 10.44 – Diagram showing the experimentally obtained distribution pattern and the effective swath width.

10.3.2.2 Rotary spreaders

The objective of calibrating a rotary spreader is to apply fertilizer at a desired application rate (kg/ha) and to obtain a uniform coverage. It is essential to establish the effective swath width and the spread pattern as they affect the amount of overlap. There are three acceptable spread patterns, flat-top, pyramid, and oval, that result in a uniform coverage if proper overlap is maintained.

Most spreaders come with a calibration kit and a set of instructions to establish spread pattern and swath width. These instructions should be followed carefully. Generally, a test area is set up as shown in Figure 10.43. Collection pans are placed according to the spacing as shown in Table 10.3. Position the row of pans so that the spreader is running at least 100 ft before it reaches them and continues to spread at least 150 ft beyond. Select the desired application rate for the fertilizer to be applied and perform the test. The application rate for each pan is then calculated based on the area of the pans and the weight of material collected in each pan. These data are then plotted in a manner similar to that shown in Figure 10.44. The effective swath width is computed from this data by locating the point on either side of the center where the application rate is one-half of that found in the center. The distance between these points is the effective swath width. The spread pattern can be visualized from the data given in Figure 10.44. If this pattern is not acceptable, necessary adjustments must be made according to the manufacturer’s instructions. Finally, the application rate can be determined in field by keeping track of the amount of material applied and the area covered.

10.3.3 Liquid chemical application

Sprayer performance is evaluated by the uniformity of coverage and spray patterns, droplet size and size distribution, and target deposition and drift.

Uniformity of coverage. The uniformity of coverage is determined by (a) the type of nozzle, (b) the nozzle spacing, (c) the boom height, and (d) the angle of the spray nozzle. As shown in Figure 10.45, the most uniform coverage is produced with a flat-fan nozzle with a wide angle, with the boom height set at the minimum recommended height. Raising or lowering the boom results in over- or under-application. The figure also shows the effect of spray angle on the uniformity of the spray pattern. For narrow spray angle nozzles, the spray pattern is much more sensitive to changes in boom height. It is generally recommended that for flat-fan spray nozzles a 60% overlap should be obtained by adjusting the boom height. (The overlap is defined as the width covered by two adjacent nozzles divided by the width covered by a single nozzle, expressed in percent.) The boom height can be calculated for a given amount of overlap and nozzle spacing. However, manufacturers’ recommended minimum boom height should be used because the actual spray width is somewhat less than the theoretical value as calculated by the spray angle and the boom height. The recommended amount of overlap for flooding flat-fan nozzles and some wide-angle hollow-cone nozzles is 100%.

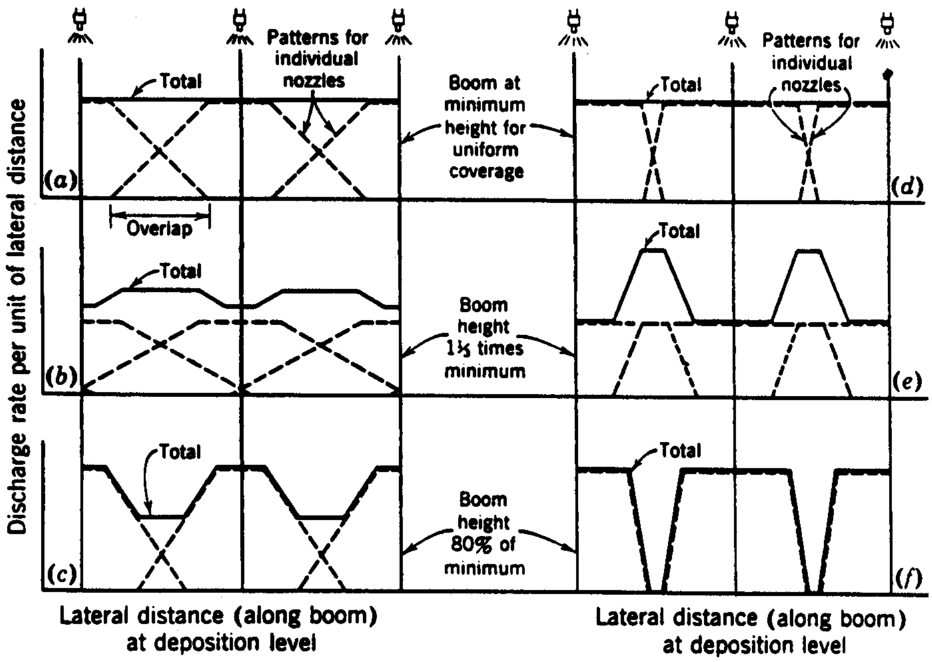


Figure 10.45 – Effect of nozzle distribution pattern and boom height on uniformity of coverage. Broken-line curves indicate distribution patterns (at the deposition level) for individual nozzles; the solid curve in each case shows the combined discharge pattern for all nozzles (i.e., the sum of the broken-line curves) (reprinted from Kepner et al., 1978).

According to the tests conducted at the Prairie Agricultural Machinery Research Institute (PAMI), Humboldt, Saskatchewan, Canada, the uniformity is affected by the nozzle pressure. Figure 10.46 shows a poor distribution pattern along the boom at low nozzle pressure corresponding to a forward speed of 8.3 km/h. The distribution became more uniform when the pressure was increased to maintain the same application rate for a forward speed of 14.6 km/h, as shown in Figure 10.47.

Other factors that result in unacceptable spray distributions include worn and damaged nozzles. Also, uneven ground causes boom height to vary thereby resulting in a non-uniform spray distribution.

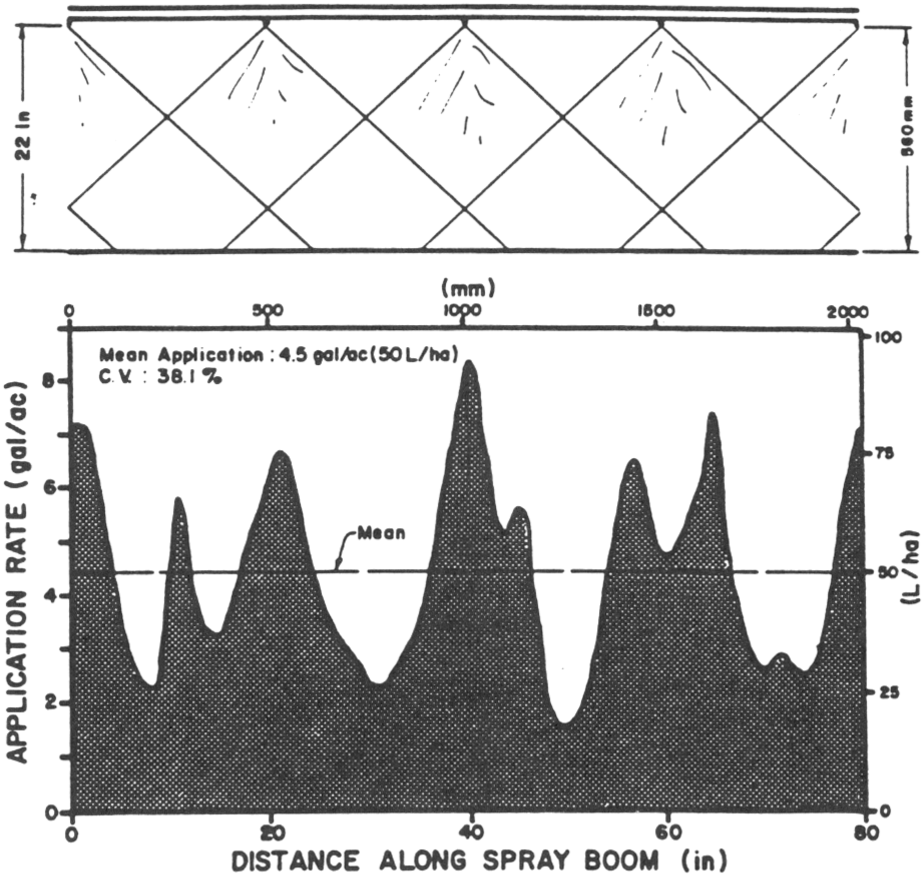


Figure 10.46 – Typical distribution pattern along the boom using number 3 nozzles at 8.3 km/h at a 560 mm nozzle height (courtesy of Prairie Agricultural Machinery Institute, Canada).

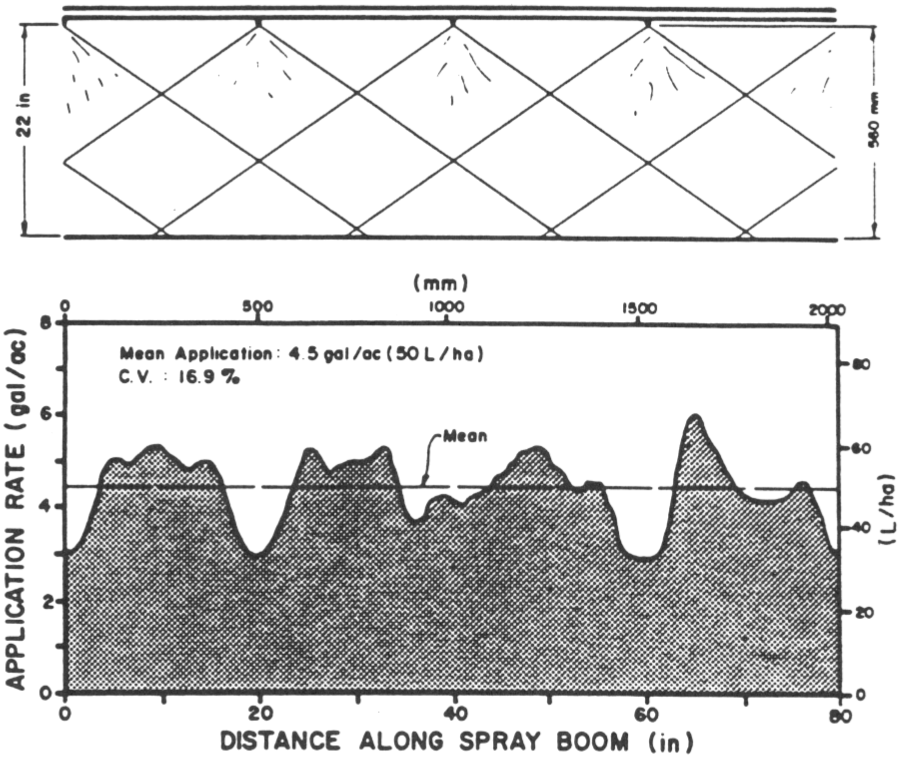


Figure 10.47 – Typical distribution pattern along the boom using number 3 nozzles at 14.6 km/h at a 560 mm nozzle height (courtesy of Prairie Agricultural Machinery Institute, Canada).

Droplet Size. Droplet size, often expressed as $D_{v.5}$ (volume median diameter), is affected by nozzle type, spray angle, flow rate, and operating pressure. Generally, the hollow-cone nozzles produce the finest droplets, flat-spray nozzles the next-finest, while the full-cone nozzles produce the coarsest spray. The droplets become finer as the width of spray increases, due to spreading of the liquid sheet to a greater angle, which produces more fines at the edges. For a given type of nozzle the smallest capacity nozzle produces smaller droplets and vice versa. Table 10.4 shows the effects of spray angle and flow rate on droplet size. As the operating pressure increases the droplet size decreases. It is, therefore, important to realize that while increasing the application rate by increasing pressure, the droplet size would decrease and may result in higher drift. Liquid viscosity and density have very little effect on droplet size in the range commonly found in agricultural application. Increasing the surface tension increases the volume median diameter (VMD).

Table 10.4. Effect of spray angle and flow rate on droplet size (Spraying Systems Co., 1991).

Spray Angle (°)	Nozzle Type (1.89 L min @ 275 kPa)	Volume Median Diameter (μ) (@ nozzle pressure of) (kPa)		
		103	275	550
40	4005 flat spray	900	810	780
65	6505 flat spray	600	550	530
80	8005 flat spray	530	470	450
110	11005 flat spray	410	380	360

Nozzle Type (275 kPa)	Volume Median Diameter (μ) (@ nozzle flow rate of) (L / min)		
	0.75	1.89	3
Std. TeeJet 80° Flat spray tip	390	470	560
XR TeeJet 80° Flat spray tip	360	460	560
TK-FloodJet Flat spray tip	370	450	540
FL-FullJet Full cone tip	—	680	770
TX ConeJet Hollow cone tip	220	360	—

Often manufacturers of spray nozzles give droplet VMD for a nozzle at a given pressure while spraying water. Droplet diameter may be estimated for a different pressure by the following equation:

$$\frac{D_{vm1}}{D_{vm2}}\left(\frac{p_2}{p_1}\right)^{1/3} \tag{10.19}$$

where D_{vm1}, D_{vm2} = VMD at pressures p_1 and p_2, respectively.

For similar nozzles and at constant pressure, the effect of different orifice size can be estimated from the manufacturers' data using the following equation:

$$\frac{D_{vm1}}{D_{vm2}}=\left(\frac{d_1}{d_2}\right)^{2/3} \tag{10.20}$$

where D_{vm1}, D_{vm2} = VMD at orifice diameters d_1 and d_2, respectively.

Often surfactants are added to increase the surface tension thereby increasing the droplet size and reducing drift. The effect of changing surface tension can be estimated from the following equation:

$$\frac{D_{vm.chemical}}{D_{vm.water}}=\left(\frac{\sigma_{chemical}}{73}\right)^{1/2} \tag{10.21}$$

where $\sigma_{chemical}$ = surface tension of the chemical, mN/m (dyne/cm).

Table 10.5. Spray droplet size and its effect on drift (Bode and Butler, 1981).

Droplet diameter, μ	Steady state fall rate, m/s	Time to fall 3.04 m in still air, sec.	Drift distance in 3.04 m fall with 4.82 km/h wind, m	Lifetime of evaporating water droplet, sec[a]	Fall distance of evaporating droplet in lifetime, m[a]
5	0.00075	3960	4815	0.04	<0.025
10	0.003	1020	1372	0.2	<0.025
20	0.012	230	338	0.7	<0.025
50	0.076	40	54.25	4	0.076
100	0.122	11	14.63	16	2.44
150	0.457	8.5	7.62	36	12.2
200	0.9274	5.4	4.57	65	38.4
500	1.158	1.6	2.13	400	>380
1000	2.133	1.1	1.52	1620	>380

[a]Air temperature, 30°C; relative humidity, 50%.

Drift and coverage. Spray drift poses a significant hazard to the environment, as most pesticides, herbicides, and fertilizers are toxic or have other undesirable effects on unintended targets. Smaller droplets tend to drift more than larger ones, because smaller droplets take longer to settle (Table 10.5). Note that as the droplet size decreases settling time increases in a logarithmic manner. Droplets that take longer to settle are very prone to drift. Every nozzle produces droplets of different sizes, but if the size distribution is very wide, a lot of droplets will be undersize and be prone to drift. It is, therefore, best to produce a narrow distribution of droplet sizes near the desired size. Generally, a balance has to be struck between the large droplets and the small droplets. Large droplets give greater penetration of the plant canopy while smaller droplets give greater coverage. Table 10.2 shows the effects of droplet size on coverage. As the droplets become smaller the coverage increases for the same application rate. For systemic herbicides larger droplets would be acceptable, but for contact herbicides or fungicides, full coverage made possible by smaller droplets is more desirable. In addition, although smaller droplets give better coverage they evaporate at a faster rate adding to the drift. Table 10.5 shows evaporation rates for different size droplets.

Research is under way to improve sprayer efficiency and reduce drift. Electrostatic charging and air-curtain sprayers are two results of the efforts in this direction. Droplets are electrostatically charged to improve their tendency to adhere to the plants thereby increasing efficiency of coverage and reducing drift. In air-curtain sprayers, the droplets are introduced in a fast moving air stream to increase penetration into the plant canopy.

10.3.4 Sprayer calibration

Sprayer calibration refers to adjusting the chemical application rate in terms of L/ha. The application rate depends on the sprayer forward speed, effective sprayer width, and the nozzle flow rate. The following formula can be used to determine the required nozzle flow rating for broadcast applications:

$$Q_n = \frac{AR\, d_n S}{600} \tag{10.22}$$

where Q_n = nozzle flow rate, L/min
AR = application rate, L/ha
d_n = nozzle spacing, m
S = sprayer speed, km/h

Once the desired nozzle flow rate is determined an appropriate nozzle may be selected from the manufacturers' catalog. The next step is to adjust the system pressure to obtain the desired flow rate. The following formula may be used to determine the desired pressure (p):

$$p = \left(\frac{Q_n}{Q_r}\right)^2 p_r \tag{10.23}$$

where Q_r = rated nozzle flow rate (L/min)
p_r = rated nozzle pressure (kPa)

For banded application, use the spray-band width or swath width for spacing in Equation 10.22. For multiple-nozzle directed spray, the value to be used for spacing is the row width divided by the number of nozzles per row. Keeping a sprayer calibrated properly is very important to maximize chemical effectiveness and to minimize environmental hazards. Sprayer controllers are now available that monitor the tractor/sprayer speed and the flow rate, and continuously adjust flow to the desired application rate.

Example 10.4

Determine the nozzle flow rate for a hollow-cone nozzle for an application rate of 200 L/ha. The sprayer speed is 10 km/h and the nozzle spacing is 50 cm. The available 0.787 mm orifice diameter nozzle is rated at 0.473 L/min at 275 kPa pressure. Determine what pressure would be required to produce the desired nozzle flow. If the nozzle produces a VMD of 200 μ at 1000 kPa, determine the droplet size at the desired flow rate. If a VMD of 350 μ is needed, determine the surface tension that should be achieved by adding surfactants.

Solution

Determine the nozzle flow rate as:

$$Q_n = \frac{200(0.5)7.5}{600} = 1.24 \quad L/min$$

Now determine the desired pressure for the given nozzle as:

$$p = \left(\frac{1.24}{0.473}\right)^2 275 = 1889 \quad kPa$$

VMD at the above pressure is calculated next:

$$d_{vml} = \left(\frac{1000}{1889}\right)^{1/3} 200 = 162 \quad \mu$$

Surface tension has to be increased to get the desired droplet size of 350m. The necessary surface tension is calculated as:

$$\sigma_{chemcial} = \left(\frac{350}{200}\right)^2 73 = 223.5 \quad dynes/cm$$

Manufacturers of surfactants should be consulted to determine the appropriate compound and its proportion to achieve the desired surface tension.

PROBLEMS

10.1 A side-dressing fertilizer unit is to place two bands per row on a crop with a 1-m row spacing. It is desired to apply a fertilizer having an apparent specific gravity of 0.85 at a rate of 560 kg/ha. If the distributor is calibrated by driving the machine forward a distance of 30 m, what mass of material should be collected from each delivery tube when the distributor is properly adjusted?

10.2 A distributor for liquid fertilizer has gravity feed through fixed orifices. The tank is 460 mm deep and is top-vented. The bottom of the tank is 610 mm above the ground and the ends of the delivery tubes are 75 mm below ground level. The metering heads (including orifices) are just below the tank, but the delivery tubes are small enough so each one remains full of liquid between the orifice and the outlet end (thereby producing a negative head on the orifice). (a) Calculate the ratio between flow rates with the tank full and with a depth of only 25 mm remaining in the tank. (b) List three possible changes in the system that would reduce the variation in rates.

10.3 A 0.95-m^3 round-bottom sprayer tank is 1.5 m long and has a depth of 0.9 m. Mechanical agitation is to be provided with four paddles 280 mm long (tip:

diameter) and 200 mm wide mounted on a shaft 150 mm above the bottom of the tank. (a) Calculate the minimum rev/min for agitating a mixture of 10% oil and 90% water. (b) If the mechanical efficiency of the power transmission system is 90%, what input power would be needed for agitation?

10.4 Under the conditions of Problem 10.3, (a) what recirculation rates would be required for hydraulic agitation at 400 kPa and 2.75 MPa? (b) If the pump efficiency is 50%, what pump input power would be needed for hydraulic agitation at each pressure? (c) Prepare a table to summarize and compare the results of Problems 10.3 and 10.4. Note the decreased recirculation rate and increased power requirement when the hydraulic-agitation pressure is increased.

10.5 A field sprayer having a horizontal boom with 20 nozzles spaced 46 cm apart is to be designed for a maximum application rate of 750 L/ha at 520 kPa and 6.5 km/h. (a) Determine the required pump capacity in liters per minute, assuming 10% of the flow is bypassed under the above maximum conditions. (b) If mechanical agitation requires 375 input watts and the pump efficiency is 50%, what should be the engine rating if the engine is to be loaded to not more than 80% of its rated power? (c) What discharge rate per nozzle (L/min) is required under the above conditions? (d) If the nozzles have 70° spray angles and the pattern is such that 50% overlap is needed for uniform coverage (i.e., spray pattern 50% wider than nozzle spacing), at what height above the tops of the plants should the boom be operated?

10.6 A field sprayer is equipped with nozzles having a rated delivery of 0.42 L/min of water at 275 kPa. The nozzle spacing on the boom is 51 cm. Each kilogram of active ingredient (2,4-D) is mixed with 80 L of water and the desired application rate is 0.95 kg of chemical per hectare. What is the correct forward speed for a nozzle pressure of 200 kPa?

10.7 A hollow-cone spray nozzle deposits most droplets between two concentric circles. Assume the diameter of the inner circle is 70% of the diameter of the outer circle and that the distribution of droplets is uniform between the circles. Plot the theoretical distribution pattern that would be expected as the nozzle is moved forward past a transverse line. Graphical solution is acceptable.

10.8 At a deposition level 410 mm below the tip of a particular fan-spray nozzle, the discharge rate-across a 20-cm width at the center of sprayed strip is essentially constant at 15 mL/min per centimeter of width and decreases uniformly to zero at a lateral distance of 36 cm from the nozzle centerline. (a) Plot the distribution curve to scale. (b) On the same graph, draw a curve for this nozzle at a deposition level 585 mm below the nozzle tip. (c) Calculate the nozzle spray angle. (d) If nozzles having this pattern are 50 cm apart on the boom, what tip height above the deposition level would give uniform coverage?

10.9 An airblast sprayer is to be operated at 4 km/h and the desired application rate is 19 L per tree. The tree spacing is 9 × 9 m and each nozzle delivers 4.0

L/min at the operating pressure of 415 kPa. (a) If one-half row is sprayed from each side of the machine, how many nozzles will be needed? (b) How many hectares can be covered with a 2-m^3 tank full of spray?

10.10 A manufacture of pressure nozzles specifies that a volume median diameter of 135 mm is obtained at 345 kPa using water. The same nozzle is to be used for a chemical whose surface tension is 50 dynes/cm. Determine the volume median diameter droplet size if the nozzle is to be operated at 525 kPa.

10.11 One hundred droplets from an atomizer were determined to have diameters in microns as shown below. Determine (a) arithmetic mean, surface, volume, and Sauter mean diameters. (b) Complete a probability distribution plot and determine number, surface, and volume median diameters.

70	250	490	160	150	370	370	330	210	500
340	210	150	340	290	110	580	760	350	290
260	270	1130	730	650	470	130	380	760	190
210	870	650	310	150	340	340	190	970	660
340	390	640	640	750	1140	450	280	160	270
250	620	150	200	520	190	440	700	280	360
140	470	470	180	1010	170	210	410	800	390
340	460	230	630	1070	570	460	550	310	170
150	150	490	100	780	370	330	520	350	250
470	540	330	150	170	370	270	370	160	190