IPARC Guide No. 1
HYDRAULIC SPRAY NOZZLES

Summary

There is a wide range of different types of hydraulic nozzle available for mechanised sprayers. Fan nozzles are used mainly for spraying herbicides and also other pesticides on crops like wheat. Cone nozzles are used mainly for insecticides and fungicides when spraying the foliage of broad-leaved crops such as potatoes. Even spray fan nozzles are used to apply a narrow band of spray. Pre-orifice nozzles are used where drift must be minimised, but it must be recognised that a change in the volume median diameter does not eliminate all the small driftable droplets.

The quality of the spray is important to achieve adequate spray coverage of the target whether it is foliage or the soil, and to minimise spray drift to non-target organisms. Nozzles will wear so the output of each nozzle should be regularly checked and worn nozzles replaced to avoid excessive volume application rates. The size of the nozzle orifice should be selected for a given volume rate at the required pressure to obtain the recommended spray quality. Avoid adjusting the pressure as this affects the spray droplet spectrum. The blocking of the orifice can be minimised by fitting a filter with the correct mesh in the nozzle body. Spray coverage can be checked with water sensitive cards placed where the pesticide should be deposited

Introduction

There are many different types of hydraulic nozzles available for spraying pesticides. Major nozzle manufacturers market several ranges, each available with an extensive set of different flow rates, distribution patterns and spray angles so that users can select the correct nozzle for a specific application. On all the hydraulic nozzles, the pressure of liquid at the orifice will have an effect on the flow rate, spray angle and the droplet spectra produced. Nozzle height above the target will influence the distribution pattern.

The nozzle TIP is usually held in a nozzle BODY by a CAP. The body can be an integral part of the boom or a separate component screwed into the boom at regular intervals along its length. On some booms the space between nozzles can be adjusted. On some sprayers only the manufacturer's own nozzle system is supplied, but most mechanised sprayers have nozzle bodies that will accommodate nozzle tips from different manufacturers. Turret nozzle bodies permit several nozzles to be fitted at each position and this allows a rapid change of tips in the field. When using a turret assembly, it is important to check that the same nozzle is used at all positions across the boom and that there is no leak at the nozzle.

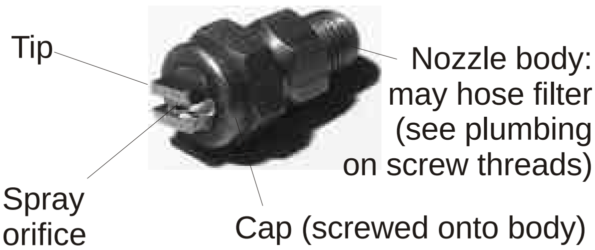

Fig. 1. *Housing the nozzle tip*

The body should incorporate a diaphragm check valve that acts as an anti-drip device. The alternative cheaper anti-drip system has a ball-valve inside a filter fitted inside the nozzle body. This type is more likely to be adversely affected by debris attached to the ball-valve, and is also removed, if the cap is loosened to change a tip, so any liquid in the boom can pour out. The cap may screw onto the body, in which case some nozzle tips need to held by a spanner as the cap is tightened, so that the direction of the spray is correctly aligned, but the trend is to have a bayonet cap. These are particularly important when using fan nozzles on a boom, as the spray sheet is automatically aligned with the boom in relation to the direction of forward travel. All the major manufacturers have their own design of bayonet cap but they are seldom interchangeable.

All the parts of a nozzle should fit together by hand without any leakage, but with some nozzle bodies and caps it is essential to have a washer seal between the tip and the body.

The nozzle tip is a small but essential part of these sprayers as it:

a) meters the volume of spray liquid applied
b) projects the spray in a particular pattern *e.g.* fan or cone
c) breaks the liquid into spray DROPLETS. The size of these droplets is usually measured as the diameter in micrometres (µm).

As small spheres of liquid the volume as picolitres should also be considered.

At the nozzle, the spray liquid is forced through a small hole or ORIFICE under pressure. The pressure provides the energy to form a sheet of liquid which then breaks up to form the spray. As the pressure is raised, there will be an increase in liquid flow, the angle at which the spray liquid is emitted is wider and the size of droplets is smaller. Formation of the sheet will be affected by the formulation and adjuvants added to the spray as well as the effect of air movement across the nozzle caused by the forward speed of the vehicle interacting with wind velocity and turbulence. Similarly some farmers may 'tank-mix' two or more products and this can affect the spray characteristics.

Ideally the pressure should be CONSTANT at the nozzle. Recommended pressures are:-

i) 1 BAR (100 kPa) for HERBICIDE sprays (but note: in some cases a label may specify a higher pressure for foliar application of certain selective herbicides).
ii) 3 BAR (300 kPa) for INSECTICIDE or FUNGICIDE sprays
iii) 2 BAR (200 kPa) may be used as a compromise between the two pressures for any pesticide.

Do not increase the pressure to increase the flow rate of a nozzle. The pressure has to be increased by a factor of 4 times to double the flow through the nozzle orifice. This can also change the quality of the spray so the operator should avoid adjusting the pressure to change the output. Always change the nozzle tip to one with a larger orifice to provide a greater output. A small adjustment of pressure may be acceptable for a small final adjustment of spray output.

The spray boom height is adjusted usually so that nozzles are positioned about 50 centimetres from the surface being sprayed. This allows the spray sheet to form and produce droplets over a particular SWATH. The width of the swath will depend on the angle of spray.

Holding a nozzle closer to the treated surface can give a narrower swath, but if the distance is greater than 50 centimetres, the swath may not be much wider as the distribution of spray droplets will be affected by gravity, while some of the smaller spray droplets can be moved downwind.

Types of Hydraulic Nozzle

The choice of nozzle type will depend on the pesticide being applied and the surface being treated. Most ranges of nozzles are available in two or three particular angles, namely 65º, 80º and 110º, but certain nozzles are available in narrower or wider than these standard angles. In arable crop spraying, the wider 110º angle is commonly used spaced 50 cm apart, as it allows the height of the boom above the crop to be lower to reduce the effect of wind on droplet dispersal. The narrower spray angle is chosen when penetration of taller crops is required.

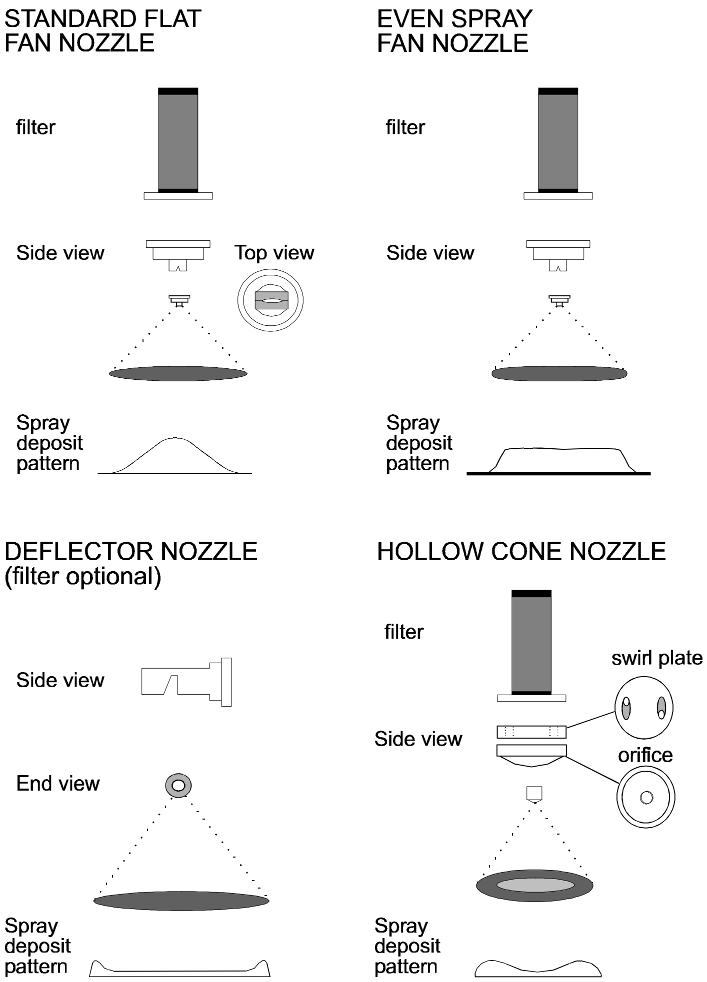

Figure 2. Conventional hydraulic nozzles and their “footprints”

Standard Fan Nozzle (F)

This type of nozzle is generally the standard nozzle tip fitted on mechanised spray booms for arable crop spraying, in particular for herbicide application. The liquid emerges from the precision elliptical or lenticular opening as a flat sheet, which becomes thinner and breaks up into the spray droplets. The pattern of the spray and the spray angle will depend on the internal shape prior to the orifice. Standard fan nozzles produce an elliptical pattern with most of the spray depositing at the centre area under the nozzle, *i.e.* a normal distribution. Therefore to achieve even coverage under the boom, the nozzle spacing has to be arranged in such a way that the patterns of adjacent nozzles overlap.

Under field conditions, even when nozzles are positioned at the correct spacing, pressure and height, some variation in distribution across the spray swath can occur due to movement of the boom and wind conditions. Fan nozzles are usually mounted offset by 5º or 10º to the direction of travel to separate the overlapping trajectories of droplets from adjacent nozzles.

Even-spray Fan (FE)

When the whole area does not require treatment, but the spray has to be uniformly sprayed across a band, the even-spray nozzle is recommended. In general, the spray droplets are smaller than if a standard fan is used at the same pressure and output. They are particularly used where a band treatment of pre-emergent herbicides along the crop row can be integrated with cultivation of the inter-row, for example in maize or sugar-beet crops.

Low Pressure Fan (LP)

Certain nozzles have been designed to provide a full pattern even when the pressure is as low as 1 bar, but users should be aware of the effect of pressure on the spray distribution. They are similar to the standard fan but were designed for herbicides applied to the soil surface. Flow rates are specified for 1 bar rather than 3 bar.

Hollow Cone (HC)

Various forms of his nozzle are very commonly found in manual sprayers used by small-holder farmers and growers. Atomisation is achieved by swirling the pesticide mixture in swirl plate or core, then forcing it through a narrow circular hole. Spray droplet formation often occurs at the periphery of a cone-shaped liquid sheet. This results in the emerging spray forming a cone, with very little spray in the centre; hence the name hollow cone. In some cone nozzles the swirl plate is integrated with the back of the orifice plate. As spray approaches surfaces from different angles, the cone nozzle most appropriate for applying insecticides and fungicides to complex surfaces such as dicotyledonous foliage. High pressures can be used to create small droplet sprays, sometimes reaching 1-2 MPa (150-300 p.s.i.), but manual equipment is more typically operated at 100 - 300 kPa (15-45 p.s.i.). Manufacturers such as Spraying Systems give data on flow rates and cone angles for nozzle configurations that are likely to be used in their principal markets (*e.g.* on tractor booms at pressures up to 2 MPa).

Cone nozzles are available in a number of forms:

1. Standard (integral) hollow cone tips (Spraying Systems: 'ConeJet' and 'VisiFlo'TX range; or Hypro Lurmark 'HollowTip': HCX series); these are cylindrical in form and protrude from the nozzle holder. The original Spraying Systems 'Conejet TX' nozzle was designed to produce an 80° spray at 689 kPa (100 p.s.i.), and 'TY' nozzles a narrower 65° cone. Narrow cone TY

– 3 nozzles were found to be optimal on tail-booms for cotton spraying since smaller sizes were prone to blockage and larger sizes would result in unacceptably high volume rates.

2. Full (or solid) cone tips: are more rarely encountered and are manufactured for spot applications: *e.g.* the Hypro Lurmark 'FulcoTip'. Applications include pest colonies and post emergence contact herbicide spraying of plant suckers, with manually operated sprayers. . They may also be used on air-assisted fruit tree sprayers. They typically produce an 80º angle of larger spray droplets than the two types above, under equivalent operating conditions.

3. Disc and swirl plate types: give a similar hollow cone of spray and as its name suggests come in two parts. These were originally labelled by Spraying Systems Dx-yz where D describes the disc (*e.g.* D2-25). Hypro Lurmark have a similar coding system, stating with the 1 mm DC02 disc (although smaller sizes are available) and similar swirl plates: thus the equivalent of the D2-25 is DC02/CR25. Commonly-used orifice discs range from the D1 to the D10 (3.97 mm), the numbers from D3 upward originally signifying 64$^{\text{ths}}$ of an inch, but this is not the case with D1, D1.5 and D2 (see Table 1). Discs are usually made from stainless steel (numbered) or engineering plastic such as polyacetal, which may be colour coded, although unfortunately not according to any international standard.

Table 1
Cone nozzle disc dimensions

Disc	**Orifice size: mm (inches)**	**Colour**	
		Spraying Systems	**Hypro Lurmark**
D1 (DC-31)	0.79 (0.031")	White	Black (non-standard)
D1.5	0.91 (0.036")	White	-
D2, DC02	1.0 (0.039")	Orange	Brown
D3, DC03	1.19 (3/64")	Green	Orange
D4 …	1.59 (1/16") …	Yellow	Red

Swirl plates (often called 'cores' in the USA) are made in engineering plastic, stainless steel or brass and are numbered, most commonly: 13, 23, 25 and 45. For hollow cone nozzles, the first digit signifies the numbers of slot-shaped diagonal holes; the second digit indicates their size relative to other swirl plates. A hole drilled in the centre of the plate, creates a full cone spray, but the numbering system here is arcane. If a liquid jet is required, a disc can be used alone - with the swirl plate removed. In combination, discs and plates can give a range of spray angles (from 15° - 115°), depending on the combination of disc, swirl plate and pressure used.

4. Proprietary cone nozzle designs fitted as standard to certain manual sprayers. These include a Chinese design (shown in Figure 3) fitted to low cost sprayers there –which are also exported to adjacent Asian countries. Although they are not widely known in the west, the Chinese Academy of Agricultural Sciences estimates that 80 million of these nozzles are in service at any given time.

5. Variable cone nozzles: are often fitted to cheaper side-lever knapsack and garden sprayers and can be set from a fine hollow cone to a jet of spray by adjusting the depth of the swirl chamber by a screw thread. Because they are infinitely variable, the spray pattern cannot be duplicated and they are not recommended for professional use. When variable cone nozzle are screwed down to their minimum settings they may produce comparably good-quality sprays. However, even unscrewing the sleeve slightly, to produce a narrow spray jet (as frequently done when

attempting to treat high branches of tree crops) results in a dramatic increase of droplet size (and thus “run-off”).

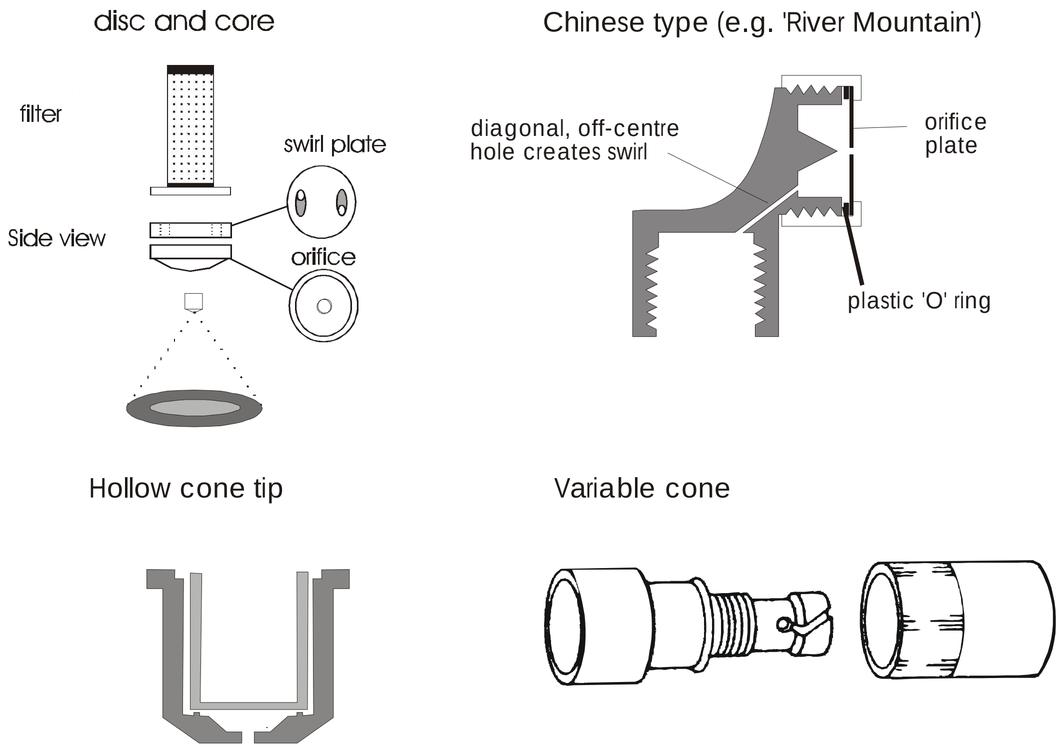

Figure 3. Some hollow cone nozzle types

Nozzles designed to reduce wind drift

Deflector Nozzles (D)

In these nozzles, also referred to as flood, impact, or anvil nozzles, a jet of liquid from a circular orifice is impacted or impinged onto a smooth plate or shaped surface immediately in front of the nozzle orifice. This type of nozzle is usually operated between 1 and 1.5 bar pressure. The jet of liquid spreads over the surface to form a sheet or film. It then emerges into an angle which will depend upon the angle or shape onto which the liquid jet impacts. Wide swath widths can be obtained from this type of nozzle and the low operating pressure)f around 200 - 400 gm that are especially suitable for the application of herbicides. Care should be taken not to exceed the manufacturer's recommended operating pressure because at higher pressures small droplets are produced, as is the case with other types of nozzle, and this contributes to undesirable drift. Correctly used this type of nozzle produces coarse or a very coarse spray quality. When used on booms, it is difficult to match adjacent overlapping spray patterns of most deflector nozzles because more spray is deposited at the edges of the spray patterns.

Large deflector nozzles may be used on aircraft for the application of certain herbicides to minimise drift. In one design the impact surface is curved to reduce the spray angle. The aim is to maintain a large droplet size by reducing the effect of air shear on the liquid emerging from the nozzles. In another design, there are two adjustable parts, the first has a series of apertures to adjust the flow rate, and the second adjustment is the angle of the impact surface to the flow of liquid through the orifice.

Another adaptation used on tractor sprayers, where there is a compressor to provide an air supply to the nozzles, has been to introduce an airflow into the liquid prior to the orifice. Provided the relative pressure of the air and liquid are set correctly the nozzle can apply low volumes (c. 100 1/ha) without having an orifice that is liable to blockage. (see air-assisted booms in Chapter 4). One advantage claimed for the system is the ability to adjust the spray quality by altering the air and liquid pressures.

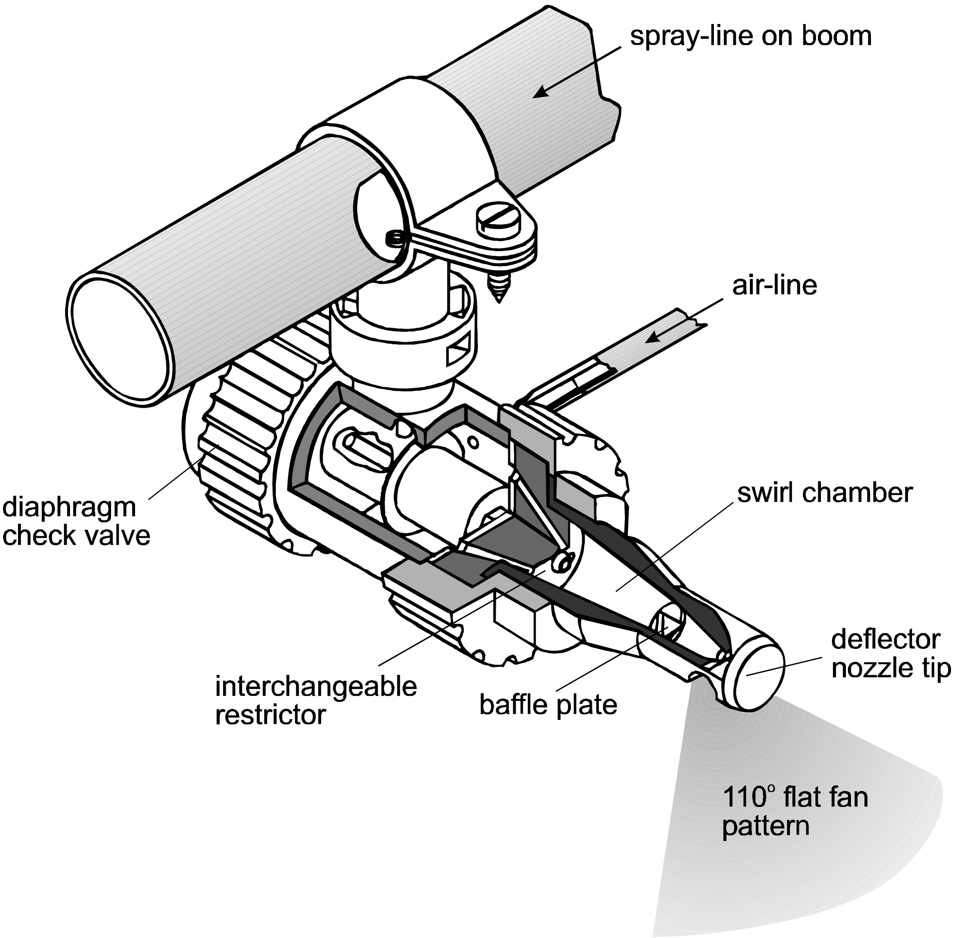

Figure 4. An air assisted deflector nozzle (the Cleanacres 'Airtec')

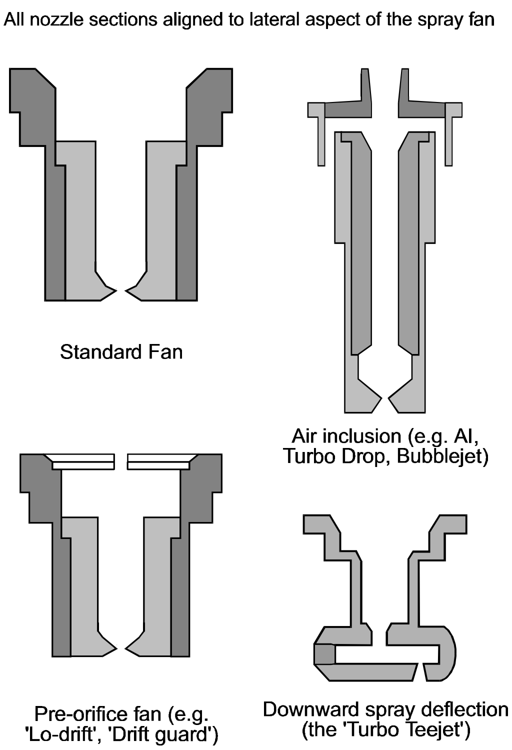

Figure 5. Variants on the hydraulic fan nozzle for reducing wind drift

Pre-Orifice Fan (RD)

With concern about spray droplets drifting away from the target surface there has been an increasing interest in reducing the proportion of small droplets produced by a hydraulic nozzle. The presence of an extra orifice before the final elliptical orifice results in a drop in pressure and on average the droplet size is larger than if a standard fan nozzle is used. The volume of the spray in droplets smaller than 100µm liable to drift is usually halved. These nozzles are marketed to produce less drift, but fewer small droplets can be a disadvantage for some pesticides. Care should be exercised when using low drift nozzles as it is possible to operate at the inappropriate spray quality, if the specified pressure is not maintained.

Air Inclusion nozzles (AI)

Pre-orifice or air inclusion nozzles have one or more opening upstream of the outlet, within the nozzle. This reduces the pressure at the final orifice and nozzles and air is sucked in by a Venturi effect to produce droplets that contain bubbles of air. These newer nozzles have become very popular with European farmers: primarily to decrease the risk of downwind drift by having fewer droplets smaller than 100µm diameter.

The Turbo Teejet (TT)

A new design of deflector nozzle, the ‘Turbo Teejet’, is now available to provide a pattern similar to a standard fan nozzle when mounted in the same aspect (see Fig. 5).

Other Nozzles

Some nozzles have been designed to produce foam by applying a liquid with a higher concentration of surfactant than in a normal spray and allowing air to be drawn into the spray in the nozzle. These foaming nozzles were tried for applying herbicides but foam can blow away in the wind. Foam nozzles are normally fitted to the end of a spray boom to mark the edge of a swath.

Whirl Nozzles

This type of hollow cone nozzle, in which the spray is emitted at right angles to the entry port has been used mostly in the USA for high volume applications and on aircraft. With large orifices they are less easily blocked compared with other cone nozzles. These nozzles are used with ground equipment applying herbicides where distribution is not critical.

Double outlet Fan

These fan nozzles have two identical orifices, one is set to spray at 30º forwards while the second is angled 30º back. When applying the same volume as a single orifice fan nozzle, the double outlet nozzle produces a finer spray. Where good coverage and penetration is needed, for example for fungicide application, the twin outlet nozzle is better than a single fan which produces too coarse a spray in one direction. They can also be used as an alternative to cone nozzles in some circumstances as the distribution of spray across the swath is better, but the small narrow orifices are prone to blockages. They are used mainly for pre-emergence herbicide application, but are also suitable for fungicide application in cereals and defoliants in some crops.

Off-set Fan (OC)

Other nozzles include the offset fan produced by machining the orifice to one side of the nozzle. These nozzles are particularly useful for covering headlands and treating areas under bush crops or trees. They can also be used in some applications, where a hose fine is used from a tractor to apply a swath to one side of the operator so he does not walk into his treated area.

Materials of Construction of Nozzles

Hydraulic nozzles were traditionally made in brass (or sometimes stainless steel), but hard-wearing engineering plastics are now most commonly used. If nozzle wear from abrasive particles is a special problem, some manufacturers supply ceramic tips inserted into a plastic mounting. If an unsuitable plastic is used in nozzle manufacture, water can be absorbed initially by the plastic affecting the flow rate by changes in the size of the orifice.

Plastic-moulded nozzles are cheaper to produce than nozzles that were previously made from brass, and in general will spray effectively for as long as brass nozzles. However the lifetime of any nozzle tip will depend on the liquid and particles that are forced through it under pressure. Where water is obtained from a stream or borehole and is contaminated with minute abrasive particles, such as sand, the orifice will be eroded rapidly. It is essential that the output of individual nozzles is checked regularly (see CALIBRATION) and a tip replaced when necessary. This is increasingly important as some pesticides are applied at very low dosage rates, but are extremely expensive. Some scientists have calculated that it is economic to replace nozzles when the output has increased by 6 - 10%. However, the percentage increase that can be tolerated will vary depending on the cost of the pesticides applied through a sprayer and the applied volume.

More expensive tips, made from stainless steel and ceramics, can be purchased, but the extra cost is only justified where extensive use of nozzles with abrasive liquids is expected or very large areas are treated by a sprayer, for example by contractors.

As effective and efficient spray application depends so much on the quality of nozzles, it is recommended that users should purchase their nozzles only from reputable manufacturers.

Colour Codes

The use of plastic nozzle tips or a plastic surround to a ceramic or metal nozzle tip allows manufacturers to colour-code the tips to indicate the flow-rate, litres per minute, at a set pressure.

Table 2 International (ISO 10625: 1996) colour codes for hydraulic nozzles.

Colour	*Flow rate (l/min. at 300 kPa)*
Orange	0.4
Green	0.6
Yellow	0.8
Blue	1.2
Red	1.6
Brown	2.0
Grey	2.4
White	3.2

Note: 3 bar pressure equals 300 kilopascals

The colour code does not indicate the type or angle, ONLY THE OUTPUT. The user must read and understand the nozzle coding, for example a BLUE fan nozzle may have a flow rate in the 1.2 1/min range, but could be an 80° or 110° angle and the output may be at 1 bar or 3 bar.

Some manufacturers also provide colour-coded caps. For the individual farmer, these can be used to identify the specific nozzles selected for his spray programme; thus the herbicide nozzles could be identified by a green cap, fungicides by a blue cap and insecticides by a red cap. This is particularly useful if the sprayer is fitted with turret nozzle mountings on the boom.

Nozzle Codes

Each manufacturer has a particular method of marking individual nozzles. For example 8001 and 01 - F80 are the equivalent nozzles from two manufacturers. The manufacturer may include a one or two-letter code to indicate the type of tip and the angle is usually indicated. However there is a code developed by the British Crop Protection Council to describe a nozzle, independently of commercial interests. This code consists of four parts:

- the type,
- angle,
- output and
- operating pressure.

Nozzle types include:

D	deflector
F	standard fan
FE	even-spray fan
RD	pre-orifice nozzles (reduced drift)
FLP	low pressure fan
HC	hollow cone
OC	off-set fan

As indicated above, the spray angles most commonly used are 65°, 80° or 110°, but other angles are available. In particular with hollow cone nozzles, it is possible to put together various combinations of disc and swirl plate to achieve particular spray angles.

The operating pressure is usually in BAR. Note 1 bar is equivalent to 100 kilopascals (kPa), 1 kgf per centimetre squared or 14 pounds per square inch (p.s.i.).

Typical examples of the nozzle code are as follows:

> **F80/0.4/3** is an 80° standard fan nozzle, emitting 0.4 litres per minute at 3 bar pressure. It is identical to the manufacturer's code example, 8001, given above
>
> **F110/1.2/3** is a 110° standard fan nozzle emitting 1.2 1/min at 3 bar.

Pressure Regulation

Increasing pressure reduces the average size and increasing flow rate (with a larger nozzle orifice size) creates larger droplets. A major source of variability with hydraulic systems is the pressure of liquid delivered to the nozzle. Pressure also affects the spray angle of hollow cone and other nozzles. Greater reproducibility can be achieved by using valves (see Figure 6) that control the hydraulic pressure and thus flow rate, at the nozzle tip: this is especially important in field trials, but can also substantially lower farmers' pesticide costs. Flow control valves are often made from engineering plastics, and are colour coded according to their operating pressure:

e.g. for the GATE 'CFValve'	Colour:
100 kPa (1 bar)	yellow
150 kPa	red
200 kPa	blue
300 kPa	green

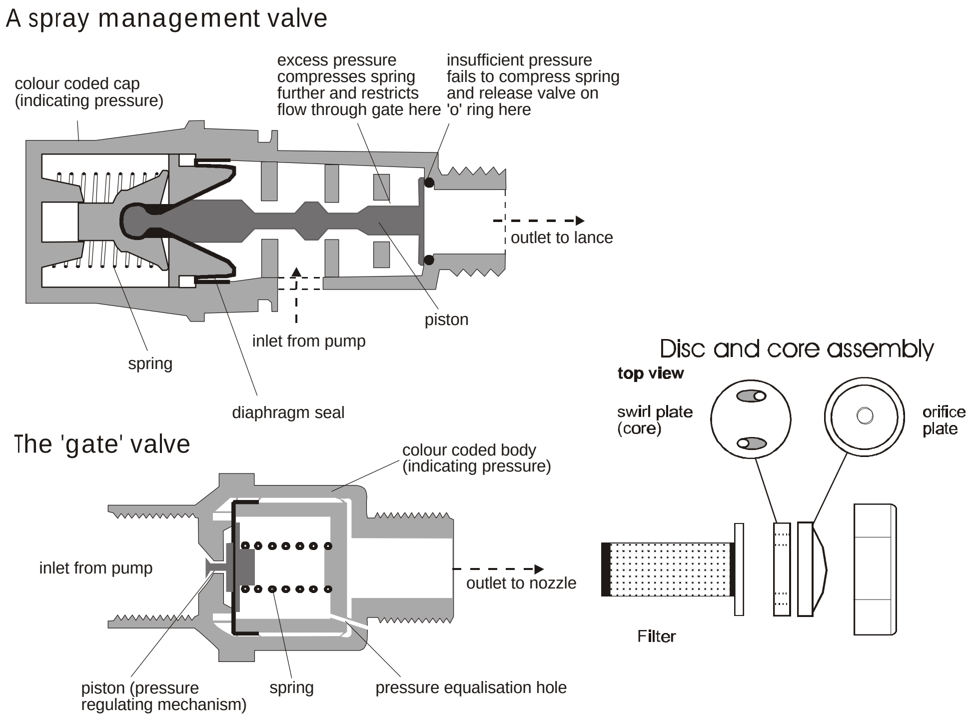

Fig. 6. Pressure regulating devices

Filtration

The small orifice in a nozzle tip can easily be blocked by small debris, so all users should filter the spray at different stages of the application system; further details are in later chapters, but there should be a filter inserted in the nozzle body. The size of the filter mesh closest to the nozzle tip should be smaller than the size of the nozzle orifice. A 50 mesh filter with 0.4mm openings is generally recommended for most sprayers. A finer mesh such as 100 mesh with 0.17mm openings is very likely to block frequently, while a coarser filter is unlikely to prevent nozzle blockages except for very high output nozzles. 30 mesh filters have an aperture size of 0.6mm.

Table 3 gives the mesh sizes of some common filters, which may be colour coded if moulded onto plastic flanges. Unfortunately, there appears to be no standard for these colour codes. Users also need to be aware that filters from different manufacturers are not always compatible with other nozzle holders. There are several types of filter, but the type usually referred to a 'thimble' has a larger surface area and is suitable for most applications.

Table 3. Some common in-line filter sizes

Mesh size (inches)	Aperture size (µm)	Colour code	
		Spraying Systems	Lurmark
16	1100	Grey	
30	530	Yellow	White
50	280	Red	Blue
80	180	Blue	Red
100	150	Green	Green

200	80	Orange

Table 3b: Guide for filter selection

Nozzle output litres per min.	Filter before pump	Filter between pump & outlet valve	Filter before nozzle
< 0.8	50	100 or 80	100
0.8 - 3.0	30	30 or 50	50
> 3.0	20	20 or 30	30

With pesticides that are particulate suspensions, the aperture size (and thus the nozzle) selected should be considerably greater than the maximum particle size in the formulation. Filter blockages are commonly an issue with biopesticides, and wherever possible is best resolved with the development of high quality formulations. There are reports of growers that use entomopathogenic nematodes frequently encountering problems with filter blockages - and some remove them completely. This practice is risky with all but the widest aperture hydraulic nozzles. For preliminary guidance we suggest a factor of x2, but in practice this will depend on the sphericity and surface properties of the particles, and should always be verified for each microbial product.

Plumbing

A practical problem, that is appreciated only rarely, is that there are no international standards for screw threads for sprayer fittings such as nozzle bodies (although the 18mm metric thread is becoming more widespread). The latter can be especially problematical when replacements are needed, and this detail should always be checked carefully. Some common thread sizes are included in Table 4. (Note: to complicate matters further, nozzle fittings may also be either "male" or "female").

Table 4. Common screw threads used for nozzles and their housings

Many European manufacturers, Berthoud, Lurmark, Jacto, Cooper Peggler (now Hardi), Field King	18 mm
Many US manufacturers, Spraying Systems (TeeJet), Delavan, Hudson, SwissMex, older Jacto	11/16" NPT
Crossmark (Malaysia)	11 mm
Older Hardi sprayers, Solo, Rega	3/8" BSP
Aspee (India), Tung Ho, Older British sprayers incl. CP	1/4" BSP

Note: other sizes are also used – some with unique threads (*e.g.* Carpi, Costa Rica). Adapters are often required in these circumstances.

Spray Quality

Not all droplets in a spray from a hydraulic nozzle are the same size. Nozzle manufacturers indicate in their catalogue the quality of spray obtained with the different nozzle tips and operating pressures. These quality assessments are based on measurements of the droplet spectrum. The droplet spectrum will affect the extent of spray coverage and the extent to which some of the droplets will be carried by the wind. In general a FINE spray is needed when insecticides and fungicides are applied to achieve good coverage of the target leaves or buds. A spray of MEDIUM or COARSE quality, with more of the volume in larger droplets, is used with herbicides to reduce the risk of downwind DRIFT on to adjacent unsprayed areas. If no information is given on the pesticide product label, always use a MEDIUM quality spray.

Laboratory determination of the spray quality is by measuring the spray droplets in flight using laser particle size analysers. The actual measurements will depend on which of the different laser systems is used to produce the data, so it is important to compare each nozzle with data from a set of reference nozzles. The spray quality for a particular nozzle can change according to the pressure; the higher the pressure, the finer the spray. For example a fine spray could be produced at 3.5 bar that could change to a medium spray when the pressure is lowered to 1.5 bar. Generally the lower the nozzle output, the average size of droplets will be smaller. When in doubt, use a MEDIUM spray.

In assessing spray quality, the whole droplet spectrum must be examined, but an indication of the size of droplets in the spray is given in the following table:

Table 5: Spray quality

Type of spray		*Volume Median Diameter*
Aerosol	- fine	< 25 µm
	- coarse	25 - 50 µm
Mist		50 - 100 µm
FINE spray		100 - 200 µm
MEDIUM spray		200 - 300 µm
COARSE spray		>300 µm

Sprays with a VMD < 100ì m used in agricultural and outdoor horticultural situations are referred to as very fine sprays. In the United Kingdom aerosols as defined above are referred to as fogs, whether produced by a thermal or cold fogger.

Aerosols are generally not used in agriculture, except to treat horticultural crops inside glasshouses and stored produce in warehouses (see Chapter 7). In open fields aerosol droplets are so small, they are liable to be blown too easily by the wind. Mists can be used in some air-assisted treatments of trees and with some ULV and VLV sprays containing sufficient involatile liquid to prevent the droplets becoming too small by evaporation.

Note:- Ideally PRESSURE is fixed in relation to spray quality required.

Checking spray coverage

The usefulness of a particular nozzle can be checked by attaching small pieces of water sensitive card to the important areas of foliage, such as the under-surface of leaves, where pests are present. After spraying with water, the coverage on individual cards can be readily seen by the blue spots where droplets have impacted on the yellow card. As the card is so sensitive to water, the foliage must be dry and the user must have dry fingers. A high humidity will change the colour of these papers to blue so they must be kept dry once the packet is opened. Water sensitive cards can be obtained through nozzle suppliers. If the special card is not available, a glossy white card, such as ‘Kromekote’ card used by printers for the covers of magazines, may be used if the spray liquid contains a colour dye. Glossy photographic paper has also been used. However the deposition of spray on a smooth paper surface will be different from that on a plant surface.

The stain of droplets on paper surfaces will always be larger than the actual droplets, as they flatten on impact with the surface. Thus if the size of stains is measured, the data has to be corrected for the spread factor, which will vary with different formulations of spray and the surface characteristics of the card. As an example if the spray contains surfactant individual droplets will spread more compared to a droplet containing only water.

As some pesticide formulations can leave a white deposit, spray deposits within a crop canopy will show up on pieces of black card which can be fixed to leaves.

Spraying can be greatly improved if an old sprayer is fitted with a new set of nozzles and an effective means of pressure control. Too often one set of nozzles is used without replacement and irrespective of the pesticide being applied. The trend in the past has also been to apply high volumes (>400 litres per hectare) through nozzles with large orifices, but as coarse sprays with large droplets may be poorly retained on many types of foliage smaller orifice nozzles and volumes of around 200 litres per hectare are more suitable. In changing to a nozzle with a smaller orifice, filtration is more important so if the nozzle tip is changed, the filter mesh may also require changing.

Calibration

Choice of Nozzle

In relation to manual carriage of water, it is preferable to keep the volume per minute **as** low as possible to avoid constantly refilling the sprayer. However, a smaller orifice is more likely to block even with an appropriate filter in the nozzle body. Deflector nozzles are used mainly for herbicides applied with knapsack sprayers, when only a single nozzle is fitted to the lance. Standard fan nozzles are used for herbicide applications usually where several nozzles are on a horizontal boom. Cone nozzles are used mainly for insecticides and fungicides where the treated surface is not uniform or flat, for example spraying leaves of a crop like, coffee, cotton or potatoes.

Objectives

The user needs to know the volume of spray applied to a particular area of crop so that the correct amount of pesticide is added to each tank-load of spray.

Box 1: Calibration Formulae

Calibration requires measurement of the nozzle output, forward speed and selection of track spacing. The general formula for calculating volume application rate (VAR) is:

$$\textbf{VAR in litres/hectare (V)} = \frac{\mathbf{k} \times \mathbf{F}}{\mathbf{T} \times \mathbf{S}} \qquad \textbf{(1)}$$

where:

F (l or ml/min.):	flow rate
T (m):	width of track spacing
S (m/min. *etc.*):	forward speed
k:	constant

Different values of '**k**' can be selected according to the way in which the flow rate and forward speed is measured. Other values can be used to adjust for other local units of measurement, and an example is given here (d) for use with vehicles with speedometers reading in statute miles per hour.

value of **k** when:	**S** is measured in:	and **F** is measured in: ml/min.	litres/min.
	a) meters/min.	**10**	**10,000**
	b) seconds for 100m	**600**	**600,000**
	c) km/hour	**0.6**	**600**
	d) miles/hour	**0.3726**	**372.6**

Whether spraying on foot or using a vehicle, it can be easier to simply keep **S** as the time taken to spray a fixed length of field (b):

1. Measure out and mark a **100m** track through the terrain to be sprayed.
2. Maintain a **sustainable** walking speed for the operator within the crop, or choose an appropriate vehicle gear ratio and accelerator position for the terrain.
3. Time how long it takes (**t:** in seconds) to travel between the markers.

For applications using vehicle mounted sprayers, speedometers are often inaccurate (and may not even register at low speeds). For locust control operations a speed of approximately 10 km/hour is appropriate. The forward speed in km/hour is **360/t**, when calculated from the method above.

It can be important to estimate the work rate (hectares treated per hour) for both trials and operations. The actual spraying time for a **1 ha** plot (where **T** is measured in m):

$$\text{Spraying time (minutes/ha)} = \frac{\mathbf{k}}{(\mathbf{60} \times \mathbf{T} \times \mathbf{S})} \qquad \textbf{(2)}$$

The total work rate depends on several additional factors, including the times taken for:

1. turning time between swaths (≈ **width of field (m) / (60 x S)** minutes);
2. mixing and measuring formulation then refilling the reservoir/sprayer tank (multiplied by the number of reservoirs to treat a hectare);
3. distance to and from the re-filling site;
4. resting (for arduous conditions) and washing.

Items 2 and 3 become increasingly significant at higher volume application rates; and can be reduced by enlarging the effective reservoir capacity (*e.g.* using back-packs with spinning disc sprayers).

To select a suitable flow rate (*e.g.* choosing a nozzle or restrictor), rearrange formula **(1)** as follows:

$$\mathbf{F} = \frac{\mathbf{V} \times \mathbf{T} \times \mathbf{S}}{\mathbf{k}} \qquad \textbf{(3)}$$

To adjust the track spacing with a given flow rate and speed, for desired volume application rate:

$$\mathbf{T} = \frac{\mathbf{F} \times \mathbf{k}}{\mathbf{V} \times \mathbf{S}} \qquad \textbf{(4)}$$

Note: The calculations above all refer to a single nozzle spray release. If more than one nozzle is used **F** refers to the total flow rate (the sum of each calibrated nozzle output). Likewise, **T** refers to the total sprayed width from a tractor boom, or true track spacing in a targeted "band" application.

Where the user can do the calculations the following technique can be used:

Method A

1. Put clean water into sprayer, check for leaks.

2. Spray water into a bucket for ONE MINUTE and measure the volume. A small graduated container is supplied with some sprayers.

3. Measure the swath width by spraying water on a dry surface.

4. Measure the distance you can walk though your crop in ONE MINUTE, while spraying.

The calculation is as follows:

$$\frac{\text{Volume per minute (litres per minute)}}{\text{Swath (metres) x Speed of walking (metres/minute)}} \quad = \text{Litres/ minute'}$$

This answer can be multiplied by 10,000 to give litres/hectare.

As an example

$$\frac{\text{0.6 litres per minute}}{\text{0.5 x 60 metres/minute}} \text{ x 10,000} \quad = \text{200 Litres/hectare}$$

Therefore if each tankload is 15 litres

200/15 = 13.3 loads per hectare.

If you need one litre of the pesticide product per hectare, then 1000 ml divided by 13.3 = 75 ml per load.

Method B

This eliminates some of the calculation by using a calibrated bottle, known as a ‘Kalibottle’ (Figure 7) to collect the spray while treating 25 metres^2. The bottle is graduated in litres per hectare. The user needs to measure a distance of 25 metres if the swath is 1 metre wide, or adjust the distance in relation to the swath width so that the same area is treated. Thus if the swath is 0.5 metres, then measure out 50 metres. The nozzle tip is removed and the cap of the ‘Kalibottle’ attached to the end of the lance. The nozzle tip is replaced, and the bottle screwed into its cap. The operator then sprays the measured area in the normal way and reads the volume of liquid collected on the bottle. In the absence of such commercial products, a clear plastic soft drink bottle can be marked off with an indelible (spirit marker) pen to create a similar calibration aid.

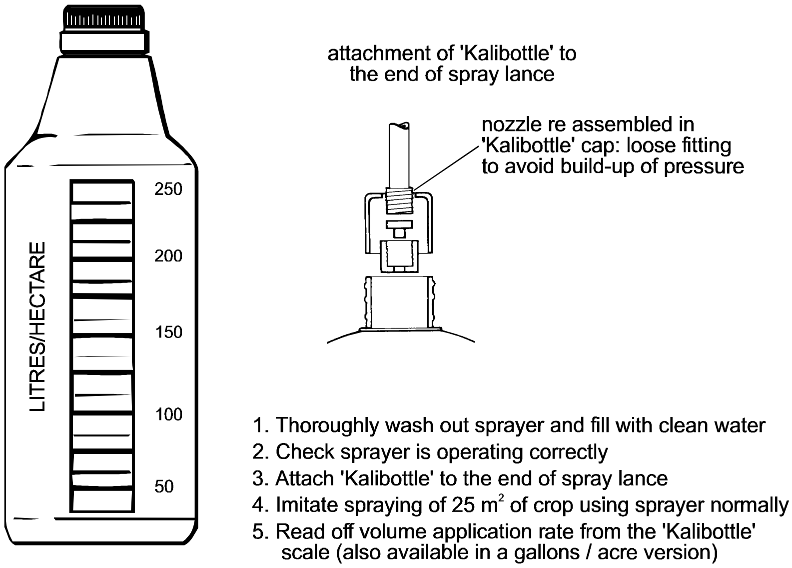

Figure 7. The ‘Kalibottle’: a device for calibration of hydraulic nozzles

Method C

Put a small volume of water into the sprayer tank and operate pump to check for leaks and that the nozzle is operating correctly. Then when all the liquid has been pumped from the tank, put in a known volume - say 1.5 litres into a 15 litre tank. Spray part of the crop and measure the number of rows treated. This number multiplied by 10 will give the number of rows treated by one tank load. From this the number of tank-loads needed to cover the whole of the crop area can be estimated. If 12 tank-loads are needed for one hectare, then the dosage per hectare divided by 12 equals the amount that has to be added to each tank-load.