THE SPRAY NOZZLE PEOPLE

TECHNICAL NOTE

What's in a spray?

The four basic spray patterns and the characteristics of spray

CALL NOW : +44 (0) 1273 400092

What’s in a spray?

As a colleague of mine is fond of saying the spray nozzle business is “just flinging water about”. Whilst that description is certainly factually correct, there is a little more to “just flinging water about” than one might first suspect. In fact, there are numerous ways in which water can be flung. How it is flung will greatly affect the properties of the spray produced and this can have a dramatic impact on the effectiveness of the spray.

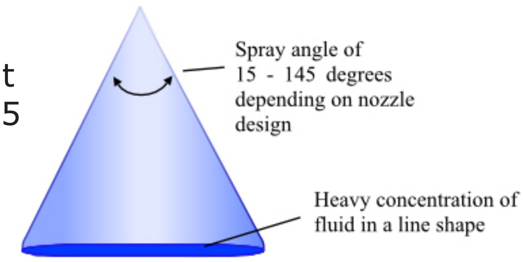
In this article we explore some of the basic characteristics of sprays and how nozzle selection affects them. This is not an extensive guide to spray dynamics, as that would fill several large volumes, but simply an introduction to allow a non-specialist to engage in a meaningful conversation with an expert manufacturer of spray systems.

The basic spray patterns

There are 4 basic spray patterns that water can be “flung” in.

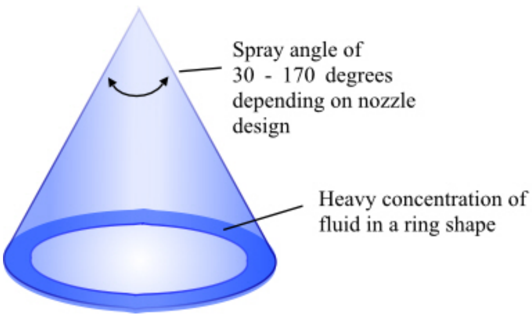
Flat Fan
The liquid is shaped into a fan shaped sheet of fluid. This can be comprised of droplets or a more or less coherent sheet of water like a waterfall. Flat fans can have a spray angle of between 15 and 145 degrees depending on the nozzle design.

Fans can be formed by a simple shaped orifice or by deflecting a spray on a shaped deflection surface.



Hollow Cone
The liquid is shaped into a fan shaped sheet of fluid. This can be comprised of droplets or a more or less coherent sheet of water like a waterfall. Flat fans can have a spray angle of between 15 and 145 degrees depending on the nozzle design.

Fans can be formed by a simple shaped orifice or by deflecting a spray on a shaped deflection surface.



Hollow cone patterns can be formed by three basic designs of nozzle

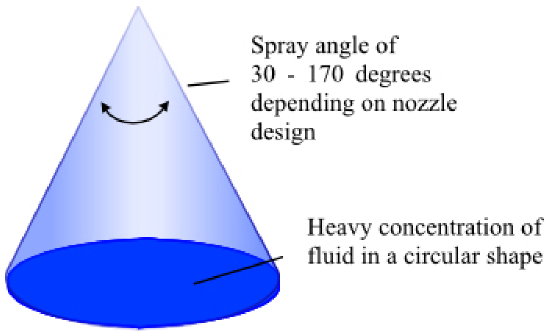
- The **axial whirl** design of nozzles where internal veins cause the fluid to swirl and prior to exiting from the orifice

- **Tangential whirl** nozzles where the fluid is set in to a whirl pool motion by having the exit orifice offset from the centre and perpendicular to the feed pipe.

- **Spiral** design nozzle (where the fluid is impacted on a protruding spiral shape breaking it apart).

Full Cone
In a full cone nozzle the liquid is broken into droplets that are more or less evenly concentrated in the cone of spray produced. Again this cone can vary from 30 to 170 degrees depending on nozzle design.

Full cones can be formed by axial and tangential whirl nozzles as well as by spiral nozzles.

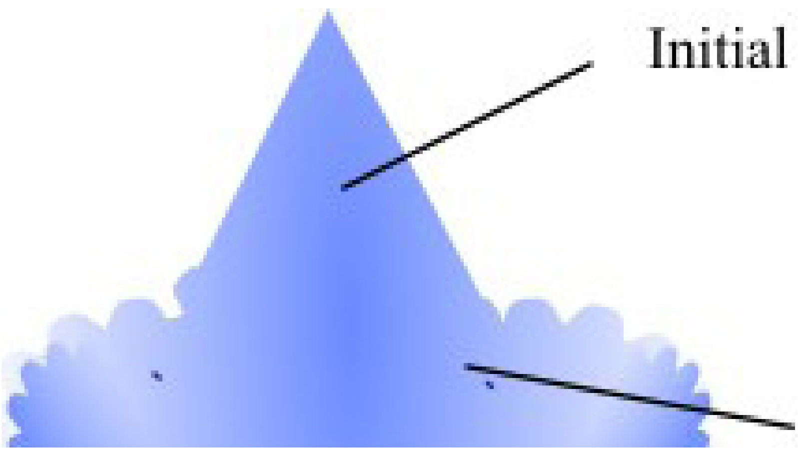


Solid stream
A simple jet of focused fluid that has no true droplets. A solid stream will be formed by forcing the fluid through a shaped orifice that focuses the spray into a jet.

One further pattern, which is not a true pattern per se, should be also be included in any discussion of sprays:

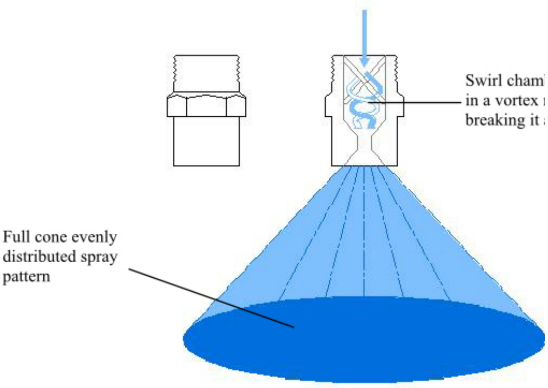
Misting/Fog
These produce a homogeneous fog or mist with little or no impact. The pattern will start out as a full or hollow cone but at a very short distance from the nozzle orifice the pattern will loose coherence and form a fog or mist.

Many hollow and full cone nozzles will eventually form a mist if sprayed at sufficient pressures. But there are two designs of nozzle that seek to achieve misting deliberately.

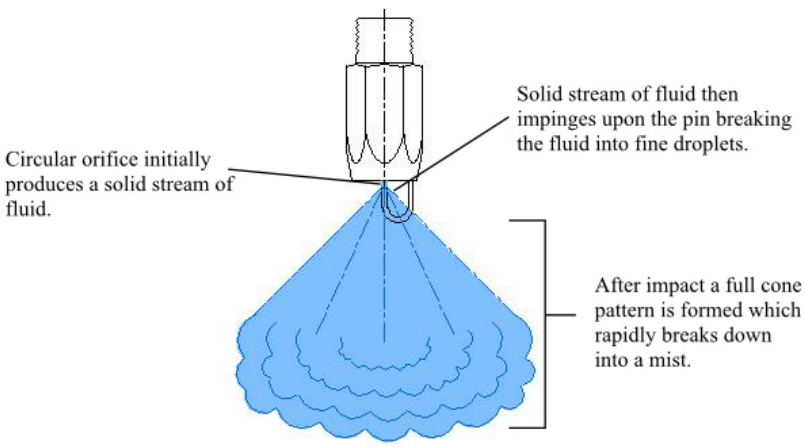


\- **The small orifice nozzle** will operate at high pressures pushing fluid through a very small opening to break it apart into a fog.

\- **The impingement nozzle** will impact a stream of fluid onto a pin directly below the orifice. This literally smashes the fluid apart into a fog.



Axial whirl full cone nozzle



Impingement misting nozzle

CALL 01273 400092

The 5 critical characteristics of a spray

The basic spray pattern types above, with the exception of misting, allow for simple trigonometry to calculate the area being sprayed. This, along with data on the flow rates at given pressures, constitutes the starting point of spraying system design. These basic coverage and dosing details though say very little about the consistency and nature of the spray. Below we examine the 5 critical characteristics of a spray, why they are important and what factors affect them.

Characteristic 1: Flow rate

Any nozzle will produce a certain flow rate at a given pressure differential. The differential pressure is the difference between the pressure of fluid in the pipe just before exit minus the pressure of the vessel it is being sprayed into so it is important to compensate for friction losses and if the fluid is being sprayed into a pressurised vessel.

The flow rate from a given nozzle can be calculated by the following formula:

$$Q = K(P)^n$$

Q = Flow rate
K = K factor for nozzle
P = Pressure differential at the nozzle
n = Is a constant that depends upon the spray pattern type.

The K factor is a unique constant for that particular nozzle which should be listed in the nozzle data table.

For many nozzles n = 0.5 which means the quotation simply becomes

$$Q = K\sqrt{P}$$

This is commonly used to apply to all nozzles but it is in fact erroneous to do so for some nozzles. In particular non-spiral design full cone nozzles and wide angle full cone nozzles will have an n exponent of 0.46 or 0.44.

A further tip is to ensure that the K factor is in the correct units. Whilst it is technically a unit-less constant it will depend upon whether metric or imperial units are being used for P and Q. There is a metric K factor and an imperial K factor for each nozzle. So caution needs to be exercised when when reading K factors from data sheets i.e. one needs to check whether the K factor is for metric or imperial units.

Specific gravity
If the fluid is heavier or lighter than water this too must be compensated for when calculating flow rates. Heavier fluids will experience a lower flow than water and vice versa.

$$\frac{Q_2}{Q_1} = \sqrt{\frac{SG_1}{SG_2}}$$

Q1 = Flow rate for a fluid of SG1
Q2 = Flow rate for fluid of SG2

When using nozzle flow rate charts that list water flow rates one can obtain the flow rates for different fluids by rearranging the equation above and setting SG1 to be 1 (for water) and using the Q1 flow rate from the chart.

$$Q_2 = Q_1\sqrt{\frac{1}{SG_2}}$$

What is interesting to note is that heavier than water fluids will spray less volume of fluid through a spray but the weight of the spray will still be heavier. This can be seen from the equation above as the flow rate (volume) is reduced by a 1/root SG factor where as the fluid weight of that spray will obviously be increased by a factor of SG2.

Characteristic 2: Droplet size

Why is this important?

The mean droplet size is actually a measure of the overall surface area of the fluid being sprayed. The smaller the droplet size the greater the surface area of the spray for any given volume of fluid. If one halves the mean droplet size of any given spray then the surface area of the spray doubles. If one quarters it then it quadruples and so on.

The surface area of a spray is a reasonable approximation to its overall reactivity.

By reactivity this can mean its ability to produce a chemical reaction or the spray's ability to absorb or dissipate heat. So in heat transfer and chemical reaction sprays the droplet size is one of the most important elements in determining how well the spray will perform.

Droplet size can also be important when considering the overall entrainment of a fluid within a gas flow. Smaller droplets will get swept along in a moving flow more quickly and if the spray is too fine this could overload mist eliminators. If operating in windy conditions then finer sprays might be blown off target so an understanding of droplet size is important.

What affects droplet size?

Pressure

A simple rule that holds for all nozzles is that the higher the fluid pressure the smaller the droplet size. For any given hydraulic nozzle the relationship between pressure and mean droplet size can be expressed as:

$$\frac{D1}{D2} = \left(\frac{P1}{P2}\right)^{-0.3}$$

Where D is the mean droplet size at pressure 1(P1) and pressure 2(P2). This gives an approximate relationship for comparing droplet sizes for any given nozzle, but there is no easy mathematical relationship for any generic nozzle as droplet size depends greatly on the design of the nozzle.

Spray pattern type

It is fairly obvious that solid stream sprays do not really have droplets at all.
Flat fan patterns may form sheets of liquid without much atomisation or may produce coarsely atomised sprays. Full cone nozzles will produce the next level of atomisation with hollow cone nozzles producing the smallest droplets.
It should be noted that there are many factors that affect droplet size but all other elements being equal the rules above will generally hold.

Spray angle

Very simply, for any given flow rate, the wider the spray angle is the smaller the droplet size will be. It's easy to understand why - larger angles sprays simply have more space to distribute the droplets and so there is less chance of recombination and a greater opportunity to atomise.

Nozzle type
The design of the spray nozzle will obviously affect spray pattern type (flat fan, hollow cone etc) and this will affect droplet size, as discussed above, but even staying within a pattern type there is variation on levels of atomisation. For example, the spiral design nozzle will produce a full cone pattern that, for a given pressure, flow rate and spray angle, will produce smaller droplets than an axial whirl nozzle. How different nozzle designs will affect droplet size can be complex and all the details can't be covered here, but it should be borne in mind that changing nozzle design type can change the consistency of seemingly identical sprays.

Specific gravity of the fluid
The specific gravity of a fluid will affect the overall flow rate achieved at the nozzle and hence will affect droplet size. For a given pressure, the higher the specific gravity the lower the flow rate, hence the lower the mean droplet size. We have software that can calculate these effects so we would advise calling us. But the formula that is generally accepted is

$$D_f = D_w SG^{0.3}$$

Df = the droplet size for the fluid in question
Dw = the droplet size for water for that particular nozzle
SG = specific gravity of the fluid

As specific gravity is often very close to 1 and the exponent is 0.3 the effect of this is generally very small.

Viscosity and surface tension
Fluids with higher viscosities than water will have higher mean droplet sizes for any given flow rate and pressure. Similarly fluids with higher surface tensions will form larger droplets. The interplay between the mechanical properties of fluids can get complex but software exists to perform droplet size calculations if the basic properties are fed in. We would advise speaking to one of our experts in order to obtain estimates for the effects of viscosity and surface tension on droplet size. But again the generally accepted formula is.

$$D_f = D_w {V_f}^{0.2}$$

Where Df = modified droplet size for the fluid in question
Dw = Droplet size calculated for water
Vf = the viscosity of the fluid (viscosity in centipoise; water = 1.0 cP)

At first it would seem that the exponent of 0.2 would indicate that viscosity has a lower effect than specific gravity but it needs to be remembered that fluids can have viscosities 1000 times that of water and still be fluids where as even a super heavy fluid like mercury only has an SG of 13.

A similar equation and relationship exists for surface tension:

$$D_f = D_w \left[\frac{S_t}{73} \right]^{0.5}$$

Where St is the surface tension of the fluid in Dynes /cm with water having a surface tension of 73 Dynes/cm at 20 degrees C.

Please note that some text books disagree on the exponent for both the viscosity and surface tension equation.

Characteristic 3: Impact and reach

Why is this important?

For applications like cleaning it is fairly obvious why the impact of a spray is an important characteristic. For other applications it may be important to ensure the spray has sufficient reach to ensure it hits its target or is sufficiently well distributed. If spraying into any kind of gas flow or in windy conditions the overall momentum of the spray will be important to know as spray drift can result in the target being missed, contamination of other areas or greatly reduced effectiveness.

What affects impact?

Pressures, flow rate and spray pattern type

Fairly obviously the higher the flow rate the greater the impact/momentum of the spray will be. But increasing pressure to increase impact will be less effective in certain nozzles. If the nozzle is very efficient at atomising the spray (for example an impingement design misting nozzle) then increases in pressure will serve to atomise the spray into finer droplets. These inherently will have less momentum and, so even with increased flow rate, the overall impact and projection of the spray will hardly be affected. At the opposite end of the spectrum is a solid stream nozzle. Here an increase in pressure will result in increased flow rate at higher velocity and no change in atomisation. As such the impact and projection will increase in line with pressure.

Increasing the fluid pressure increases the overall internal energy of the fluid. How much of this increase in energy is used to atomise the spray and how much is used to increase momentum and impact depends very much on the nozzle being used. General rules of thumb are that solid stream nozzles are the most efficient at transferring energy into momentum, followed by flat fans, then hollow cones, then full cone nozzles. It should be noted that often nozzles will be discussed as being very energy efficient. This often means they are very efficient at using internal fluid energy to atomise the fluid and so in this respect are very inefficient at energy transfer.

Characteristic 4: Actual patterns vs theoretical pattern

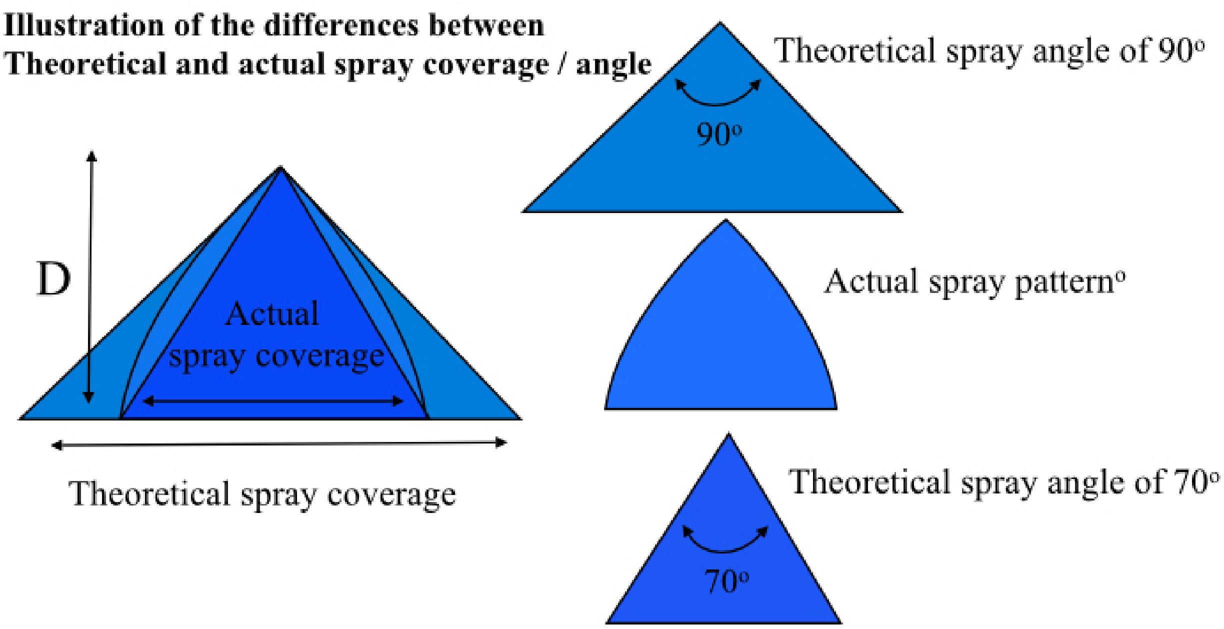
Why is this important?

Often only a specific area will need to be targeted with a spray and so the overall pattern needs to be calculated. The theoretical spray pattern calculated by basic trigonometry will often be different from what happens in reality.

Factors to consider

The effects of wind and gas flow
This will clearly affect the resultant pattern. The amount of drift that will occur will depend upon the droplet size, spray momentum and, of course, the direction of spray. This can be hard to calculate but most nozzle manufacturers will have software that can at least approximate a resultant pattern.

The effects of gravity
The idealised geometric cones and fans will only hold for a certain distance from the orifice. How long the pattern holds will depend on the nozzle being used, the flow rates and the pressure but at a certain distance gravity starts to curve in the spray pattern resulting in a smaller impact area than the theoretical pattern. Again this can be hard to calculate so specialist software may need to be deployed for truly accurate coverage figures.



Pressure
Some nozzles maintain a steady spray angle regardless of pressure. Others will have patterns that vary with pressure. In particular tangential whirl design nozzles will increase their angle of spray as pressure increases. This is because they work by forming a whirlpool of fluid within the nozzle which then is ejected by centrifugal forces into a hollow cone pattern. As pressure increases the centrifugal forces increase, lowering droplet size but increasing the angle at which they are dispersed. Conversely, a spiral design hollow cone nozzle will produce more or less the same spray angle regardless of pressure as it works by shearing the fluid into droplets by impact on the spiral shape.

Viscosity
The viscosity of a fluid may affect the spray angle produced. Fluids that are less viscous than water will tend to have a wider angle and vice versa. The effect is generally small but worth checking if precise spraying is required. We have software that can calculate this effect if necessary.

Specific gravity
As noted above in the section on flow rates the specific gravity of a fluid affects the overall flow rate through the nozzle. Heavier fluids experience a reduced flow rate but the overall weight of the spray will be increased for any given pressure. This means that the theoretical pattern will actually hold better as the spray has more momentum. One can also think of this as the spray consisting of larger droplets with less energy being used to atomise the spray.

Characteristic 5: Liquid distribution

The overall area pattern produced is generally not completely uniform. Some nozzles produce more even patterns than others so, for example, not all full cone patterns of 1 meter diameter will have the same liquid distribution even if the overall flow rate is identical.

Why is this important?

For applications like coating or moistening any localised areas of smaller of higher fluid distribution may result in problems. These types of application necessitate even spray patterns. Conversely some applications may actually require deliberately uneven patterns of distribution. For example, in fire fighting applications the presence of heavier concentrations of liquid in certain parts of the overall pattern helps give the spray momentum, helping to penetrate thermal currents and deliver the lighter smaller droplets in other parts of the pattern to the fire.

What affects liquid distribution?

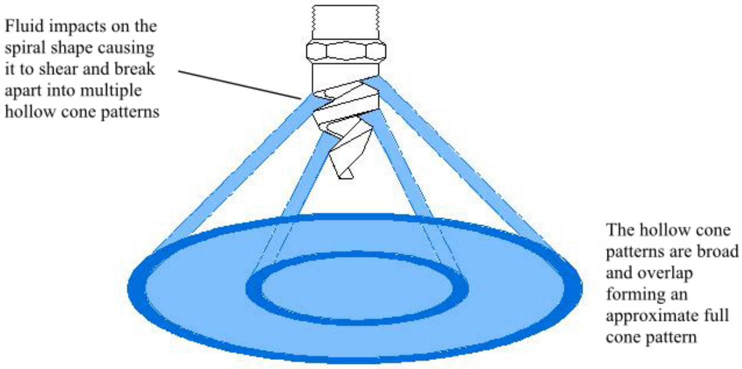
This is essentially all down to the design of the nozzle. As mentioned above not all nozzles will produce the same distribution of fluid even though their theoretical spray patterns are identical. Some general rules of thumb that can be applied are:

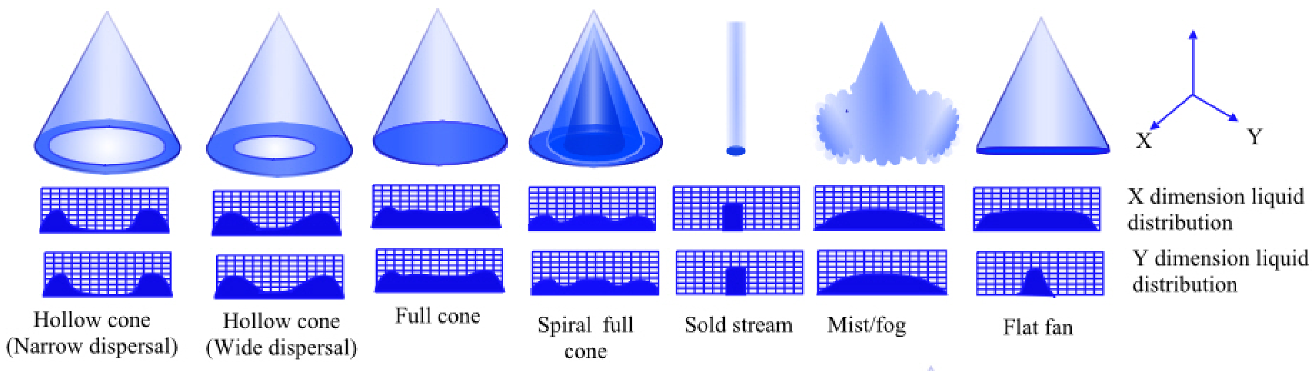
- Spiral nozzles will produce concentric rings of spray that make their full cone pattern resulting in rings of concentration.

- Tangential whirl nozzles can be configured to produce wide or thin hollow cone patterns depending on design.

- Flat fan nozzles will produce a strip of spray but this will taper at each end meaning some overlapping may be required to form an even spray.

- The narrower the spray angle the more evenly distributed the liquid will be. As there is less opportunity for the fluid to spread out and form localised areas of higher concentration.

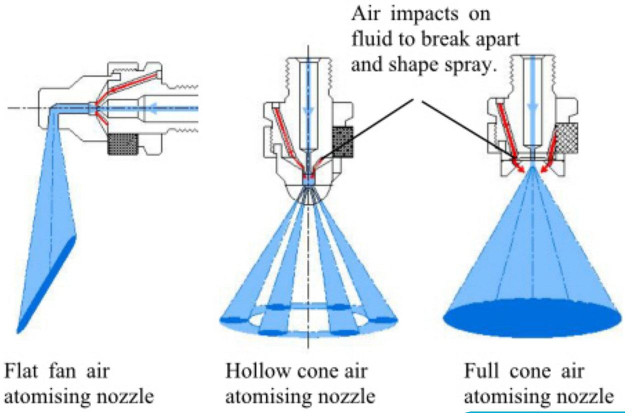




Liquid distributions for a variety of different spray patterns

Notes for air atomising nozzles

The discussion so far has been confined to hydraulic nozzles. Hydraulic nozzles rely entirely on the internal energy of the fluid being sprayed to break it apart into droplets and form the spray pattern. Air atomising nozzles, on the other hand, impact compressed air onto the fluid to break it apart and form the pattern.



Various air atomising nozzles

The introduction of a secondary source of energy into the system changes the rules outlined above completely.

Droplet size
The level of atomisation is no longer primarily a function of liquid pressure and pattern type (although these still do have some effect). Rather it is almost entirely down to the amount of air being used. The higher the air pressure and flow rate the smaller the droplets will be. This means that even very low flow rates at low fluid pressures can be finely atomised.

Impact and reach
Air atomising nozzles will always produce very fine droplets and so will be low impact, but the reach of these fine sprays can be greatly enhanced with the presence of air. Hydraulic misting nozzles will have used up most of the internal energy of the fluid being sprayed to break it apart leaving little for projecting the fluid forwards. This means that fine sprays from hydraulic nozzles will have a very small forward projection before they are at the mercy of air currents. Not so with air atomising nozzles. The compressed air from such nozzles can be used to help project even very fine spray over many metres.

Liquid distribution
As air atomising nozzles produce very fine droplets the distribution of fluid is generally very even (see above). Furthermore, the air is used to shape the pattern rather than the centrifugal forces in a hydraulic nozzle. This means there is far less opportunity for bigger droplets to concentrate in centrifugal rings.

Conclusions

Water can, it seems, be “flung” in a variety of different ways. Indeed spray nozzle manufacturers will boast catalogues with literally tens of thousands of different nozzles. Most of these will be variations on the basic designs discussed above but nonetheless getting the correct nozzle to produce the spray with the optimum characteristics for your process is not a simple task.

This brief article is unlikely to enable the reader to make a completely informed decision on exactly which nozzle will produce the precise spray required for any given process. It will however, enable the start of a meaningful conversation with a specialist manufacturer. Good nozzle manufacturers will have software to enable quick droplet size, impact and reach calculations to be performed for their range of products. So at the very least this article should enable the reader at least to appreciate what information a vendor will need to make the necessary calculations. It should also arm the reader with enough information to detect those that have, how shall we say, a “less than perfect” understanding of their product.

Ivan Zytynski
Spray People Group