Design of Farm Machinery

Prof. Hifjur Raheman
Agricultural and Food Engineering Department
Indian Institute of Technology Kharagpur
Week – 09

Lecture 43 : Atomizers

Hi everyone, this is Professor H. Raheman from the Agricultural and Food Engineering Department. I welcome you all to this SWAYAM NPTEL course on the Design of Farm Machinery. This is lecture 43, where I will cover topics related to atomizers. The concepts that will be covered are atomization of liquid chemicals, classification of atomizers, and calibration of a sprayer.

As the name suggests, atomization means it will atomize the liquid coming from the pump. So, you pressurize the liquid to pass through a small hole, thereby breaking the liquid into droplets. The main objective is to increase the surface area of the liquid. How do we do that? By breaking the liquid coming from the source. So, the liquid will be broken into smaller droplets, allowing us to cover more area. During atomization, what we do is impart energy to the liquid to break it into smaller droplets. Thereby, it can overcome surface tension, viscosity, and inertia. When it overcomes these forces, it becomes free to break into finer droplets. So, what are the different atomizers available? Atomizers are classified based on the form of energy applied to produce atomization. They could be pressure atomizers, rotary atomizers, or pneumatic atomizers. So, out of these, pressure atomizers are most commonly used in agriculture. So, in these atomizers, pressure energy is used to break up a liquid jet. So, pressure atomizers are otherwise known as nozzles. So, usually we call it a nozzle that produces several different spray patterns depending on the pressure and the hole size. Now, the different atomization methods are hydraulic pressure atomization, which relies solely on liquid pressure to atomize the liquid without the assistance of air or other gases. So, it is the pressure energy that is utilized. So, compared to air-assisted or other advanced atomization methods, hydraulic atomization typically produces larger droplets. Then, air-assisted atomization uses compressed air to help break the liquid into smaller droplets. The addition of air improves the atomization process, resulting in smaller and more uniform droplets compared to pressure atomization. Then, the other method is ultrasonic atomization, where high-frequency sound waves (ultrasound) are used to break up the liquid into droplets. Ultrasonic atomization produces extremely fine droplets. So, out of these methods, the most common method, as I said in the beginning, is hydraulic pressure, which is most commonly used. All others are not as widely used.

The figure I am showing here is a rotary atomizer. So, you can see there is a disk. This is to be rotated. So, the liquid will fall on the disk. So, because of the centrifugal force, the liquid will spread on the periphery of the disk. So, basically, in a rotary atomizer, the energy to produce droplets comes from a rotating wheel. It could be a wheel, a disk, or a cup. So, with the increase in speed, smaller droplets are produced. So, rotary atomizers are not commonly used in agricultural applications compared to pressure nozzles. So now, if you look at this: if d is the droplet diameter in micrometers, ω is the angular speed of the rotating disk or plate in radians per second, capital D is the diameter of the disk or cup in millimeters, γ is the surface tension of the liquid in millinewtons per meter, and ρ is the density of the liquid in grams per cubic centimeter, then Rotary atomizers - this diameter of the droplet can be related to these parameters. You can see, $d = K\frac{\sqrt{\gamma/D\rho}}{\omega}$. So, K is a constant with a value of 3.76.

So, if you look at this now, it is a function of all the operating parameters, like the diameter of the disk, the RPM at which the disk is rotating, and the type of liquid used meaning its surface tension and density. So, all these factors are included. These rotary atomizers are also called controlled droplet atomizers. They are called so because they produce droplets that are more or less uniform in size compared to other atomizers. Now, if I look at the equation that has been given: for a given setup - meaning a given disk, given RPM, or a given liquid - if you look at this equation, it is nothing but a constant divided by RPM. So, it is the rpm which is controlling mostly for a given set for the diameter of the droplets which are produced. So, d is equal to a constant divided by rpm. Higher the rpm lesser will be the droplet size. So, you can have a plane disk, you can have a cup disk or you can have cambers. If you provide 45 degree camber, then the droplet size is further reduced than what we get in a plane disk. So, reduction can go up to the tune of 13 per cent. You can have the serrated edges. The camber which is provided, you can give some serrations. So, that will further decrease the droplet size that means, you will get a narrow range of droplet size.

So, these are two different models of spinning disk sprayer. If you look at the figure, you can see there is a handle, the handle has to be hold by the operator and there is a bottle which will carry the liquid to be sprayed and there is a plate - atomization disk, atomizer disk. So, the liquid has to come from the bottle to this atomizer disk and the disk has to be rotated. And here the rotation is made by the use of a DC motor and the DC motor gets power from batteries which are held in this handle. So, there is this on-off switch. So, the moment you switch on this, the current will flow to the DC motor, DC motor will start running and the liquid will fall by gravity. And you will get the desired droplet size by controlling the rpm. Now the problem here is since you are hanging a bottle at the end so, that may create problem during operation. Because for a longer time the operator may not be comfortable, he will feel fatigue.

So, to overcome that one, so, the next model which I am showing is - the bottle is not at the bottom rather it is at the at the end where the handle is there. So that it is balanced. At the upper side, the bottle is there and the lower side, motor is there. And the rest of the things are same. The water will or the liquid to be sprayed will come through a pipe to the spinning disk or the atomizer disk and then the atomizer disk is to be rotated by a DC motor. The principles for working these two spinning disk sprayer are same. Only from the ergonomic point of view, they have modified this model.

Now, the most commonly used atomizer is your cone nozzle. Cone nozzle when I said, a nozzle basically comprises of four things one is the nozzle body, then the nozzle - then the swirl plate, then the nozzle cap and then nozzle tip. The main body, you can see here, the main body is this one. Inside this there is a filter and there is a swirl plate and above that there will be orifice and then through the orifice the liquid will come out of this. So, this together is called nozzle and depending on the holes - orifice means there is a hole and swirl plate means a plate which has holes either it can be drawn vertical holes or tangential holes. To get a hollow cone nozzle, we have to have tangential holes. So that, it will it will give a rotational effect. In a cone nozzle liquid is forced through a swirl plate. Swirl plate having one or more tangential helical slots or holes, then it will come to the swirl chamber. So, an air core is formed as the liquid passes with a high rotational velocity from the swirl chamber through a circular orifice and then it is forced to pass through the tip, through the orifice it will pass. So, thereby what we will get is a spray where we will find the spray is concentrated on the periphery and the inner side which can be hollow. That is why it is called hollow cone nozzle.

The thin sheet of liquid which is emerged from the orifice owing to the tangential and axial components of velocity and a solid cone pattern can be achieved by passing the liquid in the swirl plate in a vertical hole not in the tangential hole. Then the entire area will be covered and we will get solid cone. In case of solid cone, the inner core is not filled with air. It is filled with liquid. So, these are the parameters, outlet parameters - output parameters you can say: spray angle, droplet size, output - they can be obtained by varying or by different combinations of orifice size, number of slots on the or the holes in the swirl plate and by changing the depth of swirl chamber and the pressure of the liquid. 1, orifice size, number of slots 2, then depth of swirl chamber 3 and the pressure 4. There are 4 parameters by combination of these parameters you can get a range of outputs in terms of discharge, in terms of spray angles, in terms of a droplet size. Now these nozzles are to be mounted, mounted to a boom. If you remember about the tractor drawn boom type sprayer there you try to fix these nozzles - series of nozzles in the boom. So, for mounting these nozzles in the boom, we have to have a simple arrangement, so that we can easily clamp it into the boom and as per our requirement we can change its spacing. So, just loosen the nut and move it. So, these are the arrangements which are provided and sometimes bayonet cap is provided. So that you can easily open the nozzle. So, these wings are there. So, you can easily open it and then you can see the tip is blocked or not. All those things can be possible and these are now available in plastic body. Then here it is shown different nozzles. So, after the swirl plate, then the nozzles have to be provided. Either cone nozzle, swirl plate (core), then disk type all those things are provided here, deflector nozzle. So, you can change the nozzles and then these nozzles will be fitted into the nozzle cap and the nozzle cap will be finally, mounted to the nozzle body. So, the complete unit will look like this. So, if you want to change it, you can just put a fan type nozzle or you can put a deflector nozzle, remove the hollow cone nozzle. So, the same nozzle body and the cap can accommodate different nozzles ok. So, there are strainers provided. You can see the strainers are provided. There are two strainers you can see. The first strainer is this one which is at the beginning then there will be a strainer provided at the end if possible. So that the orifice is not clogged, because we have already provided a strainer at the output from the tank. So, straining is a continuous process and is required so that the nozzle should not clog.

Then fan type nozzle, the other important nozzle is a fan type nozzle. So, regular fan type nozzles are used for most solid applications. That means, if you want to apply on the surface, complete surface coverage is required, then you prefer to have fan nozzles instead of hollow cone nozzles. But this, but this type of nozzle is not suitable for covering the foliage - crop foliage. So, how it works? When two jets of liquid they strike each other at an angle greater than 90 degree then what will happen, a thin sheet will be formed in a plane perpendicular to the plane of the jets. The internal shape of the fan nozzle is made in such a way that the liquid from a single direction will be curving inwards. So, that the two streams of liquid they meet, they meet at a lenticular or elliptical orifice. The shape of the orifice is particularly important in determining not only the amount of liquid emitted, but also the shape of the sheet which will be emerging through it, particularly the spray angle.

Now, these nozzles produce a tapered edge flat fan spray that requires overlapping of pattern to obtain uniform coverage. So, the spraying angle varies from 65 to 110 degree with 80 degree being the most commonly used. Nozzle spacing is generally 50 centimeter on the boom. The boom height varies with spray angle and the amount of overlap desired. So, these are the two factors which will control what should be the boom height so that we can get an overlap of 50 per cent, 60 per cent, 100 per cent that can be controlled.

Now, deflector nozzle. It's similar to your water coming from the pipe and you are putting your finger in front of the pipe. So, just like while watering the garden. So, what happens? A fan shaped spray pattern is produced when a cylindrical jet of liquid passes through a relatively larger orifice and then it strikes at a high velocity on a smooth surface at a high angle of incidence.

If you look at this one, this is the orifice through which liquid will come and it will strike in this surface. Similarly, here liquid is coming here and it will strike this curved surface. So, you will get and if you look at this one that is more clear. Liquid is coming striking the surface then getting deflected.

So, after striking the surface what will happen is : a smooth surface will be obtained at a high angle of incidence. A smooth surface will be obtained which is in the form of a fan. The angle of fan depends on the angle of inclination of the surface to the jet of liquid. Now, the droplets which are produced by this nozzle they are greater than 250 micron, micrometer VMD and there is usually more spray at the edge of the fan less spray at the inner core. It works nicely at low pressure.

So, how to select a nozzle? What are the parameters we will consider while selecting a nozzle? So, obviously, we do not want drift. Drift means the liquid which is sprayed is not falling on the target rather than it is transported to other distance. So, that is called drifting.

So, we do not want drifting. So, drifting is common or possible when the droplet sizes are smaller. So, when the droplet sizes are bigger, then drifting is not a problem. The other factor is, if you want to avoid drifting, you just increase the droplet size. That means, for a given orifice, you can just decrease the pressure, but if you provide a droplet size much bigger than what is required, then it will not stick to the leaf. It will flow from the leaves, which is called runoff. So, while selecting a nozzle, you should keep in mind what the actual droplet size you should maintain is and what pressure is required for that. Otherwise, as I said, if the droplet size is bigger or smaller, then it will affect the efficacy, and spray drift will occur. For example, if the size of the spray particle is doubled—for example, from 250 to 500 microns - with the same volume of spray, the number of droplets produced will be one-eighth of the number of spray droplets produced earlier. So, that is another factor you want to consider, because it affects how much area you are going to cover for a given volume of liquid.

Then, the fan nozzles. They are the most common type of nozzle used in agriculture for surface application. And they are used for spraying pesticides, both banding - that means over and between rows - and for broadcasting applications. They fall into several categories: one is standard flat fan or even flat fan, low-pressure flat fan, and extended-range flat fan. Then, hollow cone nozzles. They are suitable for applying liquid chemicals to the foliage because the droplets are finer and can enter into the crop foliage easily. The operating pressure is from 40 psi to 100 psi, and they have a higher potential for drifting. Since the droplet sizes are small. So, the drifting is there. It is more likely that there will be drifting. Then, flood nozzles are popular for applying suspension fertilizers where clogging is a potential problem. These nozzles produce large droplets at a pressure of 10 psi to 25 psi, and nozzle spacing, orientation, and release height should be set such that we will get 100 per cent overlap.

Then, a question arises: how do you specify a nozzle, nozzle specification? It is basically specified by four parameters: one is the type of nozzle, that means whether it is a fan type, hollow cone type, solid cone type, or deflector nozzle type. Then, the angle of spraying; the second one is the angle of spraying; the third one is the quantity sprayed, that means flow rate - how much is the discharge rate and the fourth one is the pressure. So, that means this flow rate is obtained at this pressure. So, these are the four parameters which are required to be specified to define a nozzle. So, it is written like this: F/110/3/3.

That means, F is the fan type nozzle, 110 is the angle of spraying, 3 is the liquid which is discharged - 3 liters per minute. Then, the last 3 is the pressure, which is in bar - operating pressure in bar. So, this is how we specify a nozzle.

Then, the most important factor is the percentage overlap. In the figure, you can see when there is overlap, what will happen: the width, theoretically calculated, is not covered. The width is reduced, and that reduced width we have to find out - what is the percentage of overlap? We express in terms of the number of nozzles, in terms of the pattern width, and in terms of the spacing between adjacent nozzles. So,

$$\text{Overlap } (\%) = \frac{\text{n}\times\text{spray width covered by single nozzle}-\text{actual spray width covered}}{(\text{n}-1)\times\text{Spacing between adjacent nozzles}} \times 100$$

When I said overlap is 100 per cent, that means this spacing will be equal to half the swath. Swath means this is your swath. Now, when I said there is 100 per cent overlap, your arrangement should be such that this is half the swath. If this is S, this will be S/2. So, that is 100 per cent overlap. Manufacturers recommend that the minimum boom height should be used because the actual spray width is somewhat lesser 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 per cent. Then another recommendation is for flat-fan nozzles: a 60 per cent overlap should be obtained by adjusting the boom height. So, the proper boom height must be maintained in order to have uniformity in coverage. So, for maintaining proper boom height, you need to know what the parameters affecting it are: the spacing between two adjacent nozzles. Parameters affecting means parameters affecting the uniform application or uniform discharge - you can say along the swath. So, the first one is your spacing between adjacent nozzles in a boom, then the angle of spraying. Amount of overlap required for uniform coverage. So, these are the three factors to be considered when deciding the height of the boom. So, again, the height of the boom also depends on the height of the crops you are going to spray. So, for a given crop, these three parameters can be controlled to set the height. So that we get more or less uniform coverage.

Then, the most important factor is calibration. Once you select the nozzle type, you must calibrate it to measure the actual discharge from the spraying outlet. This must match the application rate. Otherwise, if someone says he has carried out spraying but does not know whether it provides the correct application rate, the spraying is meaningless. So, you must apply the correct amount of liquid. For that, we must initially set the pressure and discharge rate. So that it matches the application rate. So, to verify whether we are getting the desired flow rate at the desired pressure, we must calibrate the sprayer. This will help to determine how many spray tanks are needed for a particular spraying job. Spray tank needed means how many times you will refill the tank. Then, the spray application varies for different crops, row spacing, and the age, height, and density of crops. This means the sprayer must be calibrated for each crop. This calibration will ensure good coverage of the target surface and the correct amount of spray without wastage. So, thereby we save time, money and it results in a more effective and efficient spraying and it protects the environment.

For calibration of the sprayer what we do is, we apply a specified rate of chemical to the target surface. A target surface could be plant, it could be soil, it could be pest. We need to measure the total spray output, output of the machine, the travel speed and the swath - width. These are the three parameters which you want to measure. Then calculate the application rate, total sprayed amount that is expressed in litre per minute. First we disengage the gear and set the engine RPM so that you are taking power from the PTO for running a pump. So, the pump should run to give the desired pressure. This is to set the pressure fast at the correct level of spraying. Then, it should match with the pressure which is required at the nozzle that means, that is recommended by the manufacturer and it varies from nozzle to nozzle. So, then once you decide - once you get the pressure, then all the nozzles which are mounted to the boom, they are to be kept open. Then we fill the spray tank with clean water, then we place measuring cylinder under each nozzle or randomly at any any one nozzle. So, to avoid personal wetting, what you can do is you can attach a piece of a plastic hose to the nozzle and place the other end into the cylinder that is also possible. Then you have to run the sprayer for 1 minute at the correct pressure with all nozzles operating. Then we measure the quantity of water collected in the cylinder - measuring cylinder and then compare this to the output specified by the manufacturer using the correct pressure. So, we maintain the pressure. So, then what is the discharge with that we measure and what is recommended by the manufacturer that we already know then we match it. And when you match it, the difference should not be more than 10 per cent ok.

If it does, then the nozzle could be worn or damaged. Then the samples which you collected for 1 minute that means, the liquid discharge you have to take for all the nozzles present in the boom. Then you sum up and then find out what is the discharge you get total discharge per minute and then you match it whether it is matching with the application rate or not. Then the other important parameter is your travel speed which is - which has to be found out because higher the speed lesser will be the application rate. We can see it covers same area at lesser time, hence, lesser liquid is sprayed. So, a change in ground speed of 10 per cent results in a change in the application rate by 10 per cent.

So, you have to adjust the travel speed at what speed you should carry out spraying that is important. You cannot carry out spraying at 15 kilometer per hour that may create again the kind of drifting because when you move fast the air will try to push these droplets. So, there may be a drifting. So, we limit our forward speed between 4 to 10 kilometer per hour depending on the field size. Then how to measure this travel speed?

So, the best way is measure a distance of 100 meter on the ground to be sprayed and then mark the start and finish position with pegs. Then select the right gear and engine revolution that is important for spraying. First you select those. Then measure the time in seconds to travel 100 meter with the sprayer attached and tank is filled half. Then, calculate the sprayer travel speed that means, distance you have already measured and you have measured the time then you try to find out the speed. Distance divided by time that will give you the speed and that speed should match with the speed at which you are intended to carry out the spraying. So, travel speed is in kilometer per hour is equal to 100 into 36 by time. So, that will give you travel speed.

Next, important parameter is the application rate. To calculate the spray application rate, we need to know what is the total sprayed amount. The sprayed amount which you collected from different nozzles, then if you know the swath width and you know the travel speed, then you can find out what is the application rate by utilizing this formula. So, in a sprayer what we do exactly is we stick to our application rate.

Once the application rate is achieved, then you should know that that application rate should be achieved at a particular forward speed or a particular boom width. So, these two factors. So, in a given sprayer boom width is fixed, you cannot change the boom width. So, it is the only the forward speed. So, when you change the forward speed, as I said your application rate will change.

So, if your application rate does not match with the particular setting, then what we do is we increase or decrease the speed. We do not change the pressure because if we increase the throttle, the speed will increase. For a particular gear, speed will increase. And if you change the gear, then your pressure will increase or decrease depending on the rpm of the PTO. So, in a calibration, first thing we look into that is we do not change the pressure because suppose application rate is not achieved we change the pressure so that more discharge will be there. So, that is not allowed because that will also affect the droplet size. So, pressure you do not vary. You just vary the forward speed that means, the speed at which it is moving. Either you decrease the speed or increase the speed so that you can achieve the desired application rate.

So, these are some of the references, and in brief, we can say we discussed different types of atomizers and why we need them. Then, we discussed the calibration of a sprayer and why it is important. In calibration, if we do not meet the application rate, what exactly we have to do is increase or decrease the throttle position, not the gear, so that it does not affect the pressure. So, this is all about atomizers.

Thank you.