Design of Farm Machinery

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Lecture 46 : Factors affecting droplet size

Hi everyone, this is Professor H. Raheman. I welcome you all to this SWAYAM NPTEL course on Design of Farm Machinery. In today's lecture, I will try to cover some of the performance parameters like uniformity coefficient, relative span factor, and in addition to that, we will discuss the factors which affect droplet size distribution and a few numericals where we will try to see how the operating parameters can be changed to meet the application rate. This relative span factor and uniformity coefficient we discussed a little bit in the last class, but I will give in detail what exactly these factors represent. So, among the measures of droplet size distribution, we have droplet diameter, which we discussed in the last class: arithmetic mean, volumetric mean, number mean, volume median diameter, number median diameter, and percentile mean diameter. So, all those things we discussed in the last class. And in this class, I will try to cover these other factors like uniformity coefficient, relative span factor, and standard deviation.

The relative span factor is a measure which is used to describe the droplet size distribution in a spray. It provides insight into the uniformity of the droplet size produced by a spraying system. So, how do you calculate it? So, for calculating, we have to find out the $D_{v\,0.9}$ and $D_{v\,0.1}$, which represent the volume median diameter corresponding to 0.9 and the volume median diameter corresponding to 0.1. From there, the volume median diameter divides the spray into 50-50 per cent in the denominator. So, utilizing that, you can find out what the relative span factor. Low RSF - what does it mean? It indicates a narrowed droplet size distribution. That means, more or less, the droplet sizes are uniformly distributed. That is required. This is often desirable for applications requiring precision, such as pesticide application, where consistent coverage is important. So, we want in our spray system, when you carry out spraying, the RSF value should be closer to - it should have a low value. Lower is better. If you get a high RSF, that means it indicates a wide droplet size distribution. That means it has a mixture of both small and large droplets. This is less desirable in some applications because it may lead to uneven coverage, increased drift potential, or variability in deposition. So, the spraying unit should be such that it should give the RSF value as low as possible.

Then the other important parameter is your uniformity coefficient. So, it is a measure of the uniformity of the droplet size distribution and is calculated using the formula: UC = VMD/NMD. That means, volume median diameter divided by number median diameter. A low UC means the droplet sizes are more consistent and there is more homogeneity among the droplets distributed from the sprayer. And this is desirable for uniform coverage and efficiency of applications, and it will also minimize drift. When the UC value is high, it indicates the presence of a few large droplets, which significantly contribute to the overall volume. This might not be ideal in applications where fine, uniform droplets are required. For example, pesticide spraying for finer coverage.

So, after these performance parameters, let us now see what are the different factors that affect the droplet size and its distribution. It could be operating parameters. Under operating parameters, we can have nozzle type, nozzle orifice size, liquid flow rate, liquid pressure, spray angle, forward speed of the sprayer, and target distance, which means the height of spraying. Then the other parameters will be your liquid properties. For liquid properties, we can change the viscosity, surface tension, and density. So, these are the parameters of the liquid. which will influence the droplet size. In addition to that, there will be environmental parameters, which I have not taken into consideration. That means, for a given day and a given spraying unit, these are the parameters we should take into consideration to determine the performance of a sprayer in terms of droplet size.

I will highlight some key findings on how these parameters influence droplet size. So, for a full cone nozzle, the droplet size is the largest, followed by flat spray and hollow cone nozzles. That means the size of droplets from a solid cone nozzle is the largest compared to a fan type or a hollow cone type. For a given flow rate, the wider the spray angle, the smaller the droplet size. That is one factor.

Then, the nozzle orifice size - for a given system pressure, increasing or decreasing the orifice size will affect the droplet size. A larger orifice size will produce larger droplets because the liquid exits from the nozzle at a lower velocity and under less atomizing force. That means the pressure and flow rate remain unchanged; only the size of the hole is altered. Larger orifice sizes are suitable for applications requiring larger droplets where drift needs to be minimized. For example, herbicide applications to prevent fine droplets from drifting.

Smaller orifice sizes, as mentioned, produce smaller droplets, while larger ones produce bigger droplets. As the liquid is forced through a smaller opening, there will be more breakage of the liquid. This results in finer droplets or a narrower droplet size distribution, with most droplets being relatively small and consistent in size.

Then comes the flow rate, which has a direct relation to droplet size. Increasing the flow rate leads to larger droplets if the orifice size and pressure remain constant, and it can result in a broader droplet size distribution. A lower flow rate will produce a smaller droplet. Lower flow rates tend to result in a more uniform droplet size distribution.

Then pressure, this has an inverse relationship effect on droplet size. An increase in pressure will reduce the droplet size. Reduction in pressure will increase the droplet size.

Similarly, spray angle I have already told about spray angle. Spray angle has inverse relationship effect on droplet size. An increase in spray angle reduces the droplet size. Wider the spray angle, lesser will be the droplet size. Reduction in spray angle will increase the droplet size.

Then comes height - target distance. Closer target distance results in better retention of small droplets and narrower and more uniform droplet size distribution and improved coverage with minimal drift or evaporation. Farther largest distance, target distance leads to shift towards larger droplets. So, a wider droplet size distribution will be obtained when you increase the target distance and it will decrease the uniformity due to droplet evaporation, drift and turbulence. These are some of the factors which will affect the droplet size.

Under liquid properties, we noted that viscosity, surface tension and density. So, as the viscosity of the liquid increases, it becomes more resistance to breaking up into smaller droplets. So, therefore, higher viscosity liquid produces larger droplets. So, if you want to increase the droplet size without changing the operating conditions like your pressure, flow rate, orfice size then you add some viscous material to the liquid to be sprayed. So, that will increase the droplet size. The low viscosity liquids flow more easily and they are easier to atomize resulting in a finer droplet size.

Then surface tension of the liquid. An increase in surface tension leads to larger droplets. So, sometimes surfactants are added to the liquid to increase the droplet size. So, liquids with a lower surface tensions are more easily atomized into smaller droplets because the cohesive forces between liquid molecules are weaker. So, this allows the liquid stream to fragment more easily into finer droplets. So, if you want bigger droplets, you add some surfactant.

Then the last parameter is related to liquid properties is your density, density of liquid. Liquid with higher density tends to produce - liquids with higher density will produce larger droplets during atomization. So, low density liquid, they break up more easily into smaller droplets during the atomization - during the atomization process. If you want to increase the density, you add some other material. So, the density will increase. Heavier material you add, density will increase and that will help in getting the bigger droplets. Or you add lighter density material. So that density and the droplet size can be decreased.

So, these are some of the relationships, typical relationships between the operating parameters. You can see the discharge rate $\frac{Q_1}{Q_2} = \left[\frac{P_1}{P_2}\right]^{1/2}$ So, that means if you increase the pressure, your flow rate is reduced. Then, $\frac{VMD_1}{VMD_2} = \left[\frac{P_2}{P_1}\right]^{1/3}$. So, when we increase pressure, pressure is inversely related to your volume median diameter, and the orifice diameter is related like $\frac{VMD_1}{VMD_2} = \left[\frac{D_1}{D_2}\right]^{2/3}$. Similarly, I said by adding surfactant - so, by adding surfactant, the surface tension of the liquid with respect to water and the volume median diameter of the liquid with respect to water are related by this relationship $\frac{VMD_{chemical}}{VMD_{water}} = \left[\frac{\sigma_{chemical}}{73}\right]^{1/2}$. So, if you want a larger droplet size - higher droplet size, then you increase this value. So, these are some of the relationships available. By utilizing this, we can adjust our system parameters so that it will satisfy the droplet size requirement.

I will try to solve a few problems where we can see how we can vary the droplet size by different operating parameters, so that it suits our desired conditions. The question is: determine the nozzle flow rate for a hollow cone nozzle for an application rate of 200 liters per hectare. The sprayer is operated in the field at a forward speed of 7 kilometers per hour, and the nozzle spacing is 50 centimeters. The 0.787 orifice diameter of the nozzle is rated at 0.975 liters per minute at 275 kilo Pascals. So, determine what pressure would be required to produce the desired nozzle flow rate?

So, the first thing is you have to calculate the nozzle flow rate. And for calculating the nozzle flow rate, what is required is the number of nozzles. So, here the number of nozzles is given as only one. That means the spacing between nozzles is given. So, 50 centimeter is the width. Forward speed is 7 kilometer per hour. So, I have to convert this one per minute. So, 50 by 100 into 7000 by 60 that will be the area covered per minute. So, I can write this as area covered per minute.

Now, in this area what is the quantity of liquid which is required to be sprayed that you can calculate, since application rate is given. So, the area which you got here that has to be multiplied with 200 liter. So, it is per hectare. So, I have to convert it into meter square - per meter square. So, I just multiply this one with 200 divided by 10000. So, this amount will be the liquid which has to be sprayed by a single nozzle unit - single nozzle. So, this comes to 1.166 liter per minute. Now, the nozzle orifice diameter is given as 0.787 and the nozzle discharge rate is 0.975 liter per minute and this discharge is at a pressure of 275 kilo Pascal, but our discharge requirement is little higher than what it is obtained at 275 kilo Pascal. So, how to achieve this discharge? So, there are two ways either you can increase the orifice diameter or you can increase the pressure.

So, let us see by increasing the pressure because we know that $\frac{P_1}{P_2} = \left[\frac{Q_1}{Q_2}\right]^2$. So, the rated value you can take as P_2 and Q_2 that means, if I put in this equation, I want to find out P_1. So, $P_1 = P_2\left[\frac{Q_1}{Q_2}\right]^2$. So, P_2 is your pressure at which the data is available like 275 is the kilo Pascal and Q_1 is the desired which is 1.166 and Q_2 is the discharge rate 0.975 raised to the power 2. So, what you get is 393.769 kilo Pascal. So, we have to increase the system pressure to this much to get the desired flow rate.

The next question is: a field sprayer is equipped with 8 nozzles spaced at 40 centimeter having a rated delivery of 0.42 liter per minute of water at 275 kilo Pascal. Each kilogram of active ingredient is to be mixed with 100 liters of water and the desired application rate is 0.6 kg of chemical per hectare. Decide the correct forward speed for the nozzle pressure of 200 kilo Pascal. If the nozzle produces a VMD of 200 micron at 275 kilo Pascal, what would be the VMD of droplets at 200 kilo Pascal? Also suggest suitable method to increase the droplet diameter without changing the operating pressure.

So, let us first find out correct forward speed. So, what is given is application rate. 100 liters of water is to be added to 1 kilogram and the application rate is 0.6 kg that means, we are going to apply 60 liters per hectare. Discharge rate is given by nozzle is 0.42 liter per minute. 0.42 liter per minute at a pressure of 275 kilo Pascal. Now, what is desired is we have to carry out spraying at 200 kilo Pascal that means, what will be the corresponding discharge?

This is the discharge - rated discharge. Now, for 200 kilo Pascal what will be the corresponding discharge? That I have to find out. So, we know that $\frac{Q_2}{Q_1} = \left[\frac{P_2}{P_1}\right]^{1/2}$. Now what is known is: this is P_1, this is Q_1.

So, $Q_2 = Q_1 \left[\frac{P_2}{P_1}\right]^{1/2}$. Q_1 is given as 0.42, P_2 is 200 kilo Pascal and P_1 is 275 kilo Pascal. So, that way we find out what is the flow rate at pressure 200 kilo Pascal that comes to 0.358 liter per minute. Now, our application rate is: if the nozzle produces a VMD of 200 micron, next question is if the nozzle produces a VMD of this much micron, what would be the VMD of droplets at 200 kilo Pascal? So, we find out $\frac{VMD_2}{VMD_1} = \left[\frac{P_1}{P_2}\right]^{1/3}$. Here DVM is same as VMD.

Now, this is equal to I can write $DVM_2 = DVM_1 \left[\frac{P_1}{P_2}\right]^{1/3}$. DVM_1 is your 200 micron and pressure P_1 is 275. So, $200 \times (275/200)^{1/3}$. So, that will be the desired diameter. So, this comes to 222.39 micron.

If the nozzle produces this, what will be the - also suggest suitable method to increase the droplet diameter. So, suitable method means if you add some surfactant then that will increase the droplet diameter that is the suitable method - suggestion for increasing the diameter. Now, the forward speed I have not discussed. So, to calculate the forward speed, what we have done is we have calculated the corresponding discharge rate to this 200 kilo Pascal. What is the discharge rate we calculated - which you obtained as Q_2 is equal to 0.358 liter per minute.

Now, there are 8 nozzles, they are spaced at a spacing of 45 centimeter. So, this multiplied by this 45 by 100, this will give you the width of coverage multiplied with the speed. Speed is I have converted to meter per minute. So, this much is the area and this has to be multiplied with application rate is 60 liters per hectare. So, 60/10000. So, this will be the quantity of liquid which will be discharged in that area. So, how it is possible?

So, this will be equal to 8 into, 8 is the number of nozzles and the discharge which is obtained is 0.358. No, this speed is not 7000 because speed is not given, we have to calculate. Suppose this is V_f. now I multiply with V_f which is your forward speed in meter per minute. So, this is your area which is covered. This has to be multiplied with this is application rate that means, this much quantity is to be discharged by 8 nozzles with a flow rate of 0.358 liter per minute.

So, now, you have to find out this V_f. So, from this equation 8, 8 will cancel out. So, what we will get is $V_f = 0.358 \times 10000 \times 100 / (45 \times 60)$. So, that way you are getting 132.59

meters per minute. So, if you convert it to kilometers per hour, it comes to 7.955 kilometers per hour. So, the first thing which I did is, since the pressure is given as 200 kilo Pascals and the discharge rate which is given here is at 275 kilo Pascals. So, first I converted the discharge corresponding to this pressure. And then, corresponding to this pressure, if I know the discharge, what is the application rate required? So, for finding out the application rate, we need to know the forward speed, and that is what is asked: what is the forward speed? So, for calculating the forward speed, what I did is, the area which is covered, assuming the forward speed as V_f meters per minute. So, this much is the area which is covered per minute.

And during that time, for that area, what will be the quantity of liquid which is sprayed? So, that I multiplied with the application rate, which is 60 liters per hectare. So, 60/10000. So, this has to come from 8 nozzles with a flow rate of 0.358, which you got by changing the pressure. So, from here, I find out what is the forward speed. So, forward speed is calculated. I hope I am clear.

Then, the next question is: a manufacturer of hollow cone nozzles specifies that for an orifice diameter of 0.787 millimeters, a volume median diameter of 135 micrometers is obtained at 345 kilo Pascals using water when the rated output is 0.473 liters per minute. The same nozzle is to be used for a chemical whose surface tension is 15 dynes per centimeter. Determine the volume median diameter droplet size if the nozzle is to be operated at 525 kilo Pascals.

So, the values which are given: volume median diameter is given for a pressure of 345 kilo Pascals. Now, what is required is: the rated output is given as 0.473 liters. So, $\frac{\mathrm{DVM_2}}{\mathrm{VMD_1}} = \left[\frac{P_1}{P_2}\right]^{1/3}$. So, DVM_2 is our requirement. So, what is the pressure? 525 kilo Pascals.

So, DVM_1 is given as 135, and the pressure P_1 is 345 kilo Pascals. So, I just put it as $\mathrm{DVM_2} = \mathrm{DVM_1} \left[\frac{P_1}{P_2}\right]^{1/3}$. So, that way, I am getting 135 multiplied by 0.869. So, 117.369. This is given for water. Now, the surface tension of a liquid is given as this. So, the volume median diameter which you got here is for water. Now, when you are utilizing a chemical whose surface tension is less than water. So, we have to utilize that equation again. $\frac{\mathrm{DVM_{chemical}}}{\mathrm{DVM_{water}}} = \left[\frac{\sigma_{\mathrm{chemical}}}{\sigma_{\mathrm{water}}}\right]^{1/2}$. So, this we have calculated as 117.369, this is in microns. So, now DVM of chemical will be equal to. Surface tension of chemical is given as 50 dynes per centimeter, and surface tension of water is 73 dynes per centimeter. So, $(50/73)^{1/2} \times$

DVM_{water}, which we just calculated. So, that way we are getting 97.135. That means we are getting a volume median diameter value in micrometers, which is less than the value for water. That means we added a surfactant to reduce the surface tension, thereby decreasing the droplet size.

So, these are some of the operating parameters and how they influence the performance of a sprayer in the field. So, by adjusting different parameters, we can maintain the flow rate or obtain the desired application rate.

So, these are some of the references. In summary or conclusion, I can say, we discussed the different factors which affect the droplet size and how they are distributed. We also discussed about how to manage these parameters so that we can obtain the desired flow rate or the desired application rate by solving a few problems.

Thank you.