Design of Farm Machinery

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Lecture 44 : Performance evaluation of sprayers

Hi everyone, this is Professor H. Raheman. I welcome you all to this SWAYAM NPTEL course on Design of Farm Machinery. This is lecture 44, where I will try to cover performance evaluation of sprayers. The concepts which will be covered in this lecture are performance of a sprayer, uniformity of coverage, Patternator - what is a patternator? And why is it used? Then a few numerical problems will be solved.

When I say performance of a sprayer, we usually refer to the evaluation of certain parameters. Those parameters are uniformity of coverage, spray pattern, droplet size distribution, target deposition, and drift. So, how do you do this? We can do this in the field or in the laboratory, but uniformity is usually measured in a laboratory by a setup called a patternator. What is a patternator? It basically comprises a set of V-shaped channels through which the liquid will be sprayed. So, the jet or the nozzle which is to be verified - the spraying unit has to be mounted on a frame at a height of 45 degrees.

We have to maintain the pressure and the discharge rate the same as required for achieving the application rate or as recommended by the manufacturer. So, we have to maintain that pressure and discharge. Then what we measure is how much discharge you are collecting. How do you collect it? When the nozzle is spraying on the channels - the V-shaped channels - the edges are very fine. So, nothing will stick to these edges, everything will fall into the channel, and at the end of the channels, test tubes are present.

So, each channel is connected to a test tube. So, whatever spraying material is falling on this channel, this channel is not horizontal, it is kept at an angle. So that the liquid which is falling on this channel will freely flow to the downside and the downside there are tubes - test tubes. So, the liquid will be collected in these test tubes. So, each channel is provided with a test tube.

So, the specifications what we can say is not fixed exactly you can vary the specifications. So, only thing is we need to maintain the height, maintain the pressure, maintain the discharge rate. These are the three parameters which are to be maintained. We can increase or decrease the length of the bed where the channels are fixed, then width of the channel either 25 millimeter or 50 millimeter that is also possible and the depth of channel we do not keep more than 10 millimeter. Then we usually provide a slope, so that whatever liquid is falling that will immediately flow to the downside. Then the setup which I am showing is the total width is 165 centimeter that means, it is more than the pattern width what we get in case of a cone type nozzle or a flat cone nozzle - a flat fan nozzle.

Then the height of spraying is kept - this height is matching with the height at which we want to operate in the field. Then the material of construction, the channels are usually made up of GI sheet. So, what we measure here is : if you look at the level of liquid which are collected in the test tubes that will give you a visual indication that whether the discharge which is done by the spraying unit is giving you uniform discharge or there is variation. So, directly it can give you visually. Then what we measure actually is; spray angle.

Spray angle how do you measure it? If you know the height from which we are spraying and you know the swath how much width it is covering. So, that is easier for us to calculate because we know which test tube is the last two test tubes. So, then you know the span or the swath and height you know. $\tan^{-1}$ (half of the swath/height) will give you half of the spray angle.

So, this is the swath which you get then this is the height, height you know, then if you measure only this portion or you can measure the total divided by 2. So, tan of this angle - this is $\tan\theta$ then $\tan\theta$ = half swath is x/H, H is the height. So, x, we measure, H is we have already fixed, keep it same as whatever boom height we maintain in the field. So, from here you can find out what will be the angle of spraying for a given nozzle. Then spray distribution, the spray collected in the tubes is to be noted down for observing spray pattern.

So, a graph is to be plotted between lateral spacings and the volume of water collected in the tubes. Then you try to find out what is the mean, standard deviation and the coefficient of variance from these observations. And ultimately what you compare is the COV value, COV value should not be more than 10 per cent if you want more uniformity. Now, this will be the pattern - pattern of spraying which will be observed depending on the type of spraying unit. So, you will get - more or less some variations will be there, but if you take the middle points then you can say the variation is like this.

So, up to certain width we are getting more or less uniform spraying and as you go towards this side or towards this side so, there is lesser discharge ok. So, this factor brings that we need to have overlapping ok. We need to have overlapping. If the patternator has sufficient width we can vary the spacing and put two nozzles and then see whether you are getting more or less uniform spraying or not by selecting suitable - by adjusting suitable spacing that is also possible. So, these points are nothing but the volume which you collect in the test tubes, then what we do is we try to find out the mean value, then we try to find out the standard deviation, s = $\sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}}$. Once you know the arithmetic mean, then we know the standard deviation, then you can find out coefficient of variation = (standard deviation/mean)×100. And that value should not exceed 10 per cent that is our target.

Next thing is : these are the outputs from 3 different nozzles, the left side is your fan type and solid cone spring pattern, the right side is your hollow cone spring pattern. So, what you observe, what you try to discuss here is the effect of nozzle type and boom height on uniformity of coverage. How uniform is the coverage when you select a nozzle like a fan type or hollow cone type or a solid cone type and then if you vary the height of spray that is boom height and then how it is affecting the uniformity.

So, if you look at this figure on the left side which is representing the profile obtained from a fan type or a solid cone type, the profile is nearly same. So, that's why I have written fan type and solid cone type. The dotted line indicates the individual spray quantity. Now, the solid line which is represented that shows the total spray available in that zone.

Now, if you look at this when the boom height is minimum. Where you want to get uniform coverage, as you can see, you are more or less getting a uniform, solid straight line. The pattern is the top spraying is narrow, and the profile is gradually increasing; the slope is gradual. Now, if you compare with a hollow cone, the top portion is widened, and the slope is steep; the slope is steep. But the height where we have kept it: we are getting more or less a constant discharge. So, from this figure, what we can say is that the total discharge is again a function of the type of nozzle.

Now, the second thing is when we try to - this is, suppose this height is where we are getting uniform coverage; if you denote it as H, now we have increased that H to 1.5 times. So, what you observe here is that there is some variation. So, the total discharge you can see is not as uniform as what you get at H. Now, if you look at this side, the variation is a little higher in the sense you are getting a peak here, again coming down, again getting a peak.

So, the variation here, the variation here, if you compare, the variation is more on the hollow cone sprayer as compared to the fan-type sprayer.

Now, the third thing is when you try to decrease the height, decrease the height of spraying. So, we reduce it to 0.8H. This one was 1.5H; now you have decreased it to 0.8H. So, if you look at, there is variation; there is no - there is no more uniform application. You can see the total discharge is like this. So, there is a good amount of variation. Now, if you look at the hollow cone side, you can see there are some spaces where you are not getting any spraying. So, if you compare these two, then what you can say is the steep-sided profiles, like the one which you get from hollow cones, they are more sensitive to change in height - sensitive to what? Sensitive to uniformity of coverage. Then if you change the height little bit your uniformity is severely affected. As compared to the fan type or the solid cone type you can see the variation is not that much. That means, solid cone type and fan type they are not that sensitive when you change the height of a spraying. The other comparison is when the slope is gradual, we require more overlapping to get uniform spraying. You can see overlap amount is this much, but for steep-sided slopes or the profiles which you get from the hollow cone, there overlap is only this amount. So, if you are selecting fan type nozzles, if you are selecting solid cone nozzles, then you have to provide more overlap. If you are selecting hollow cone nozzles, then you have to provide lesser overlap. That means, you can increase the spacing. So, you can cover more area.

Spacing when you increase obviously, speed remains same. So, area covered per unit time will increase. So, your field efficiency will increase. So, if I summarize this one then the most uniform coverage is produced with a flat fan nozzle, raising or lowering the boom results in over or under application that we discussed. Then for steep-sided profiles that like the one which is obtained for hollow cone nozzles, they are far more sensitive to boom heights variations than the narrow topped and gradual sloping profile what we obtained for fan type or solid cone type. And more overlap is required for profiles having narrow tops and lesser for stiff sided slopes.

The uniformity of coverage now depends on four factors, what is the type of nozzle, then what is the nozzle spacing, then what is the boom height, then angle of spray. These are the four factors which are going to affect the uniformity of coverage. So, when you are designing a spraying unit, these are the factors which one should keep in mind so that it will help in better designing the spraying unit. And then the other factor is of course, how much overlapping you want to give. So, overlapping in case of flat fan nozzle 60 per cent, in case of a flooded nozzle we require 100 per cent overlap.

And taking the boom height one can calculate the given amount of overlap and nozzle spacing or if you know the nozzle spacing from there you can find out the height to get the desired overlap. So, the thing is manufacturer recommended the boom height, if you follow that boom height then you may not get the discharge what is mentioned. So, first you have to check the discharge and then you try to adjust the height, so that you will get the desired overlap. In a hollow cone nozzle we require 100 per cent overlap. So, these are some of the factors which you keep in your mind.

Next thing is let us now see how to utilize those knowledge which we discussed for last two three classes related to sprayer or chemical application equipment.

So, some of the problems I will try to solve now, the first one is a field sprayer with 18 nozzles spaced 40 centimeter apart, this is to be operated at 3.4 kilometer per hour. If the nozzles are set to operating - set to operate at a pressure of 11.6 kg per centimeter square for an application rate of 1.12 meter cube per hectare, calculate the discharge rate per nozzle. That is part 1, then part 2 is the spraying angle is 75 degree, calculate the height of spray from the ground so that each nozzle spray pattern or the deposition level is 50 per cent greater than the nozzle spacing.

The first one: what is given is application rate, application rate is given as 1.12 meter cube per hectare. The numbers of nozzles are given as 18 with a spacing of 40 centimeter. Assuming that there is no overlap, because overlap percentage is not given.

So, we just multiply 18 by 40. So, that will give you the width. So, the width of coverage will be equal to 18×40, which means 7.2 meters. Now, this is operated at a forward speed of 3.4 kilometers per hour. That means, in 1 minute, the area covered will be $(3.4 \times 1000/60) \times 7.2$ meters. So, that will be the area covered, which comes to 408 square meters. Now, what is the quantity we want to spray in this area? So, the application rate is given; you just multiply 1.12/408. As this is per hectare. So, I have divided by 10000. So, that becomes per square meter.

So, that way, we are getting 45.696. 45.696 liters per minute - this is the discharge. So, now, this discharge is to be made by 18 nozzles. So, each nozzle will give a discharge; each nozzle will have an output = 45.696/18. So, that way, you are getting 2.538 liters per minute. So, this is the discharge rate.

Now, the second bit is the spray angle is given. Now, what is asked is to calculate the height of the spray from the ground so that each nozzle spray pattern at the deposition level is 50 per cent greater than the nozzle spacing. So, the nozzle spacing was given as 40 centimeters. So, 50 per cent extra means you now require a swath of 60 centimeters. So, this is the height.

So, this swath is 60 centimeters. So, that means this is 30 centimeters. So, what will be this angle of spraying? It is given. This is 75/2. So, tan (75/2) = 30/H. So, this H has to be found out. So, H will be equal to 30/tan 37.5. So, that way you will get 39.096 centimeters. So, this is the height if you maintain it, then you will get an overlap of 50 per cent at a spraying angle of 75 degrees. I hope I am clear.

Then, the next problem is the application rate of insecticide for paddy plants is 1.1 kg per hectare. 0.9 kg of insecticide is to be added to 90 liters of water. And the sprayer is equipped with nozzles having a rated delivery of 0.5 liters per minute at a rated pressure of 2.7 kg per centimeter square.

If nozzles are spaced 60 centimeters apart, find the forward speed of the sprayer to get the desired application rate. Now, the desired application rate is with water if you find out. So, 0.9 kg is to be mixed with 90 liters. So, obviously, 1.1 kg will be mixed with 110 liters. That means this is the quantity which is to be applied per hectare.

Now, the discharge rate per nozzle is 0.5 liters per minute. Let the number of nozzles be N; So, 0.5 multiplied by the number of nozzles will be the discharge. So, before that, we have to find out how much area is covered per minute. So, Vf - suppose Vf is the forward speed - and spacing is not given. Sorry. Spacing is given as 60 centimeters. So now, it becomes: N is the number of nozzles multiplied by 0.6, the spacing between nozzles. So, that will give you the width multiplied by the forward speed. V is in meters per minute – V = Vf is the forward speed in meters per minute. So, that means this much is the area which is covered per minute, ok. This has to be applied through the number of nozzles, say N. Now, the discharge is 0.5 liters per minute multiplied by N. So, this should be equal to this.

So, N, N will cancel out. So, now, V will be equal to 0.5/0.6 So, 0.5 that is 110 per hectare was there. So, you can convert it to divided by 10,000. So, that it becomes 110/10000.

Now, the area which you are getting is in meter square because this is in meter this is in meter. This area × 110/10000 should be equal to this much. So, I have missed this part has to be multiplied because this is giving you the area, area multiplied with the application rate that will give the quantity of liquid which will be discharged and that should come from the N number of nozzles. So, each nozzle is giving a discharge of 0.5 liter per min. So, that way if you equate then $0.5 \times 10000/110$.

So, that way you are getting 75.75 meter per minute which will be equal to 4.54 kilometer per hour. Next problem is at a deposition level of 430 meter below the tip of a particular fan type nozzle, the discharge rate across a 20 centimeter - across a 20 centimeter at the center of sprayed strip is essentially constant at 15 milliliter per minute. Now, milliliter per minute per centimeter of lateral distance on each side of this 20 centimeter center strip, the discharge rate per centimeter of width which decreases uniformly to 0 at a lateral distance of 36 centimeters from the nozzle center line. So, let me draw first the data which are given. This is the central line of spraying Now, there is another nozzle here.

So, what is given is 20 centimeter at the center that means, 10 centimeter this side, 10 centimeter this side there you are getting uniform spray. And what is the height of spraying? This is given as 430 millimeter and lateral distance is given as 36 centimeter from the nozzle central line that means, from here to this distance is 36 centimeter here to this distance is 36 centimeter. So, now, we find out what is the angle of spraying?. So, if it is you denote the total angle of spraying is theta then tan $\theta/2$ will be equal to height sorry, this swath - half of the swath is 36 centimeter.

So, 36/43, that will be the angle. And the angle will come as 79.87 degree - θ, I am talking about θ. This is not $\theta/2$. So, θ will be equal to this much. Now, what is asked is calculate the nozzle spray angle. So, we calculated the nozzle spray angle that means, whatever you get here just multiply with two that will give the nozzle spray angle. Now, second one is nozzles having this pattern are 50 centimeter apart that means, this distance is 50 centimeter.

What peak height above the deposition level would give uniform coverage. That means, you have to change the height of spraying and that is what he is asking. So that, this the profile should reach here. Initially it was here, now we have shifted to this one. How to do that?

By increasing the height. So, what is that height? Now, let the height be H'. So, we know the angle because the angle does not change. So, $\theta/2$ we know, which is nothing but 79.87/2, and then we do not know the height. Then we have to find out this swath - the new swath, you find out.

The total distance is 50 centimeters, and this distance is 10 centimeters where you are getting a uniform spray. So, then the rest will be 40 centimeters. So, $\tan(\theta/2) = 40/H'$. So, $H' = 40/\tan(\theta/2)$. So, that way you are getting 47.78 centimeters.

So, if you raise the height from, say, 430 to 477.8 millimeters, then we will get the deposition - the pattern to give uniform coverage. So, this is how you have to solve it. Then, another problem where, in a mango orchard, the trees are planted at 9 by 9 meter spacing. The chemical is to be applied at the rate of 19 liters per tree using a sprayer. Each nozzle is adjusted to give a discharge of 4 liters per minute at a pressure of 415 kilo Pascals, assuming the speed of travel as 4 kilometers per hour.

The number of nozzles required if one half row is sprayed from each side ok. One half of the row is sprayed from each side and the number of mango trees which can be covered at one time the tank capacity is 3.5 meter cube. So, area of each plant will be equal to area of each plant covered will be equal to $9 \times 9 = 81$ meter square. Now, the length is 9 meter. Suppose this is the area the length is 9 meter. So, to cover this 9 meter what will be the time required? Because forward speed is given.

So, we are covering 4000 meter in 1 hour. To cover 9 meter $(1/4000) \times 9$ this is an hour if you want to make it per minute you can do this by multiplying 60. So, that will give you the length covered. So, in this length what is happening - what it is saying? If one half row is sprayed from each side that means, in this length half of the spray will be available.

So, half of the spray means this is the spray and each plant is requiring 19 liter. So, that means, half of this is has to be spread in this time. So, 19 liter's half that means, 9.5 liter is to be applied in this much minute. So that way we are getting 70.37 liter per minute. Now, what is happening?

The application rate is 4 liter per minute per nozzle You are applying 4 liter per minute. So, to apply this much, number of nozzles required will be 70.37 by 4 that way you will get 17.59. Roughly around 18 nozzles. So, 18 nozzles on one side, the other side 18 nozzles, so there will be 36 nozzles.

So, total number of nozzles will be 18×2, so 36. 36 nozzles will be required to carry out or to apply 19 liter per tree. Next question is how many mango trees are to be covered if the tank capacity is 3.5 meter cube. So, simply you can calculate that 90 liter - one tree is requiring 90 liter. So, 3.5 meter cube will cover how many trees?

So, 3.5/19, 3.5 × 10,000/19. So, that way you are getting around 184 roughly. So, this much is the capacity and then one tree is consuming 90 liter. So, just divide it then we will get the number of mango trees which can be covered by a tank capacity of 3.5 meter cube. So, these problems which we solved that will help you in designing a sprayer.

These are some of the references. Finally, I can say that we discussed the performance of a sprayer, particularly limited to the laboratory, which is a patternator. Then, we compared different profiles obtained from different nozzles and how the uniformity of coverage depends on the operating parameters. A few numerical examples will help you design a spraying unit. That is all.

Thank you.