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NUMERICAL AND VOLUMETRIC FREQUENCY OF SPRINKLER DROP-SIZE FROM WATER DISTRIBUTION RADIAL CURVE PART II: EXPERIMENTAL VALIDATION

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ABSTRACT

In the previous Part I, a mathematical model was proposed to correlate the travel distance of the drops from the irrigation sprinkler with the drops water volume. In the current work, the mathematical model was transformed in an indirect method to calculate the sprinkler drop-size spectra and hence in an algorithm implemented in a spreadsheet. These spectra were compared with two experimental data groups available in literature. The comparison between the predicted and experimental values of the two cumulative droplet-size distribution curves, considering the maximum absolute difference (d_{KS}), showed a good precision with a Kolmogorov-Smirnov statistic d_{KS} equal to 0.076 and to 0.111 respectively, depending on two experimental data groups used.

Keywords: sprinkler irrigation, mathematical modelling, ballistic model, nozzle, spreadsheet.

INTRODUCTION

The knowledge of numerical and volumetric frequency of sprinkler drop-size, or sprinkler drop-size spectrum, is very important to help irrigation designers and farmers in the selection and design of sprinkler irrigation systems in order to obtain good distribution uniformity and high efficiency of irrigation water use ([1], [2]).

To analyse droplet size distribution different methods may be used. The optical methods using laser or spectrometer ([3], [4] [5]) are substituting the pellet method (see for example [6], [7], [8], [9]) that is time-consuming, but the new methods require very expensive devices. Von Bernuth and Gilley [10] proposed an indirect method for the determination of droplet size spectrum, based on water distribution radial curve obtained in laboratory, using data reported by Kohl [11] for model validation.

In Part I [12] a mathematical model to obtain sprinkler drop-size spectrum from the water distribution radial curves was proposed. It is based on a simplified ballistic model for the determination of the droplet trajectory and on amathematical approach to determine the droplet population from the experimental water distribution radial curve.

MATERIALS AND METHODS

Application of the mathematical model

As shown in Part I [12] the procedure to calculate the sprinkler droplet-size spectrum can be implemented in a spreadsheet for ease of use.

The first step begins with finding the minimum, x_{tmin}, and maximum, x_{tmax}, travel distances, which depend on the sprinkler characteristics and are deducible from the experimental water distribution radial curve.

The analytical ballistic model by Lorenzini [13] is applied by varying the diameter D_i with a chosen step, for example 0.02 mm, beginning from a droplet of diameter D_1 equal to the minimum travel distance x_{tmin} and ending with a droplet of diameter D_{max} equal to the maximum travel distance x_{tmax}.

The equation $I = f(x)$ of the water distribution radial curve is found by applying a sixth-degree polynomial regression to the experimental radial curve. Subsequently, the polynomial $x_t = p(D)$ [12] is determined by the creation of a plot of x vs. D and applying a fourth-degree polynomial regression; thus, the derivative $p'(D)$ will be a polynomial of degree three.

For each diameter D_i, the derivative $\left(\frac{dn}{dD}\right)_i$ is found by applying $\frac{dn}{dD} = \frac{12}{D^3} \cdot f\left[p(D)\right] \cdot p(D) \cdot p'(D)$ [12], and hence, as the range of each class of diameters ΔD_i is fixed (in this case 0.02 mm), a column with the values of the number of droplets Δn_i belonging to each class is found according to $\Delta n_i = \left(\frac{dn}{dD}\right)_i \cdot \Delta D_i$ [12].

From $\Delta V_i = V_{Di} \cdot \Delta n_i = \frac{\pi}{6} D^3 \cdot \Delta n_i$ [12], another column is calculated showing the values of the water volume ΔV_i for each class. As the total number of droplets $N = \sum \Delta n_i$ [12]is defined, it is easy to find the numeric frequency for each class $f_{ni} = \frac{\Delta n_i}{N} \cdot 100$ [12] and thus the numeric cumulative frequency, F_{ni}, for each class, that is, the ratio between the total number of droplets from the first class to the ith class and the total number of droplets, N:

$$F_{ni} = \frac{\sum_{j=1}^{i} \Delta n_j}{N} \cdot 100 = \sum_{j=1}^{i} f_{nj} \qquad [12].$$

Calculation of the percentage ratio between the water volume ΔV_i obtained from $\Delta V_i = V_{Di} \cdot \Delta n_i = \frac{\pi}{6} D^3 \cdot \Delta n_i$ and the total volume $V_t = \Sigma \Delta V_i$ gives the volumetric frequency for each class $f_{vi} = \frac{\Delta V_i}{V_t} \cdot 100$ [12].

Finally, as for the numerical cumulative frequency, it is possible to define the volumetric cumulative frequency, F_{vi}, for each class $F_{vi} = \frac{\sum_{j=1}^{i} \Delta V_j}{V_t} \cdot 100 = \sum_{j=1}^{i} f_{vj}$ [12]. From the columns of the cumulative number frequency and the cumulative volume frequency, plots of each vs. droplet size can be drawn. These diagrams are the desired droplet-size spectra.

Experimental data

For the model validation both Kohl's data, used by von Bernuth and Gilley [10], and droplet-size spectrum data obtained by Li [14] were used, each corresponding to laboratory tests designed to yield the pertinent water distribution radial curves.

RESULTS AND DISCUSSIONS

The experimental data reported by Kohl [11], used by Von Bernuth and Gilley [10], were used for both the water distribution radial curves and the droplet-size spectra. These data refer to the Nelson F32/F33 sprinkler tested with different nozzle diameters and different pressure values, for a total of five combinations.

Figure-1 shows a comparison between the two cumulative frequency curves, one calculated from the number of droplets and the other one from the volume, for the 3.18-mm nozzle diameter and 400 kPa pressure. The comparison shows that 50% of the droplets had a diameter < 0.49 mm (NMD = Number Median Diameter), while 50% of the water volume consisted of droplets with a diameter < 1.5 mm (VMD = Volume Median Diameter).

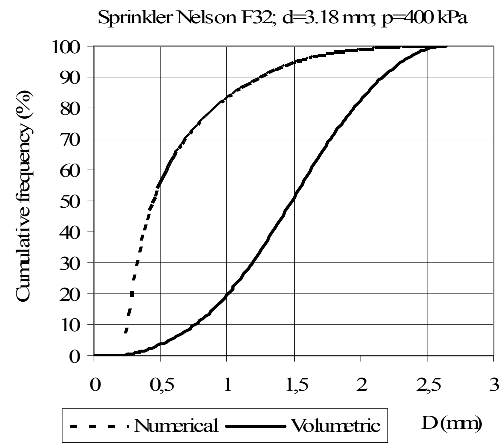

Figure-1. Cumulative number frequency and cumulative volume frequency vs. droplet size for the Nelson F32 sprinkler with a 3.18-mm nozzle diameter at 400 kPa.

Two facts can be noted: 1) the VMD is about three times greater than the NMD, a detail that also occurs with other nozzle diameters and operating pressures; 2) for the analysis of wind drift, evaporation and soil-surface crust formation, the cumulative-volume-frequency curve is the more interesting of the two. For this reason, the results presented hereafter refer only to the cumulative volume frequency.

For each combination (nozzle, diameter, and pressure) the procedure proposed herewas applied to obtain a calculated cumulative frequency, which was compared against the experimental cumulative frequency given by Kohl [11] and the one calculated by Von Bernuth and Gilley [10] (Figures 2, 3, 4, 5, and 6).

To compare the calculated frequency curve and the experimental curve, the Kolmogorov-Smirnov KS statistic d_{KS} was used[1].

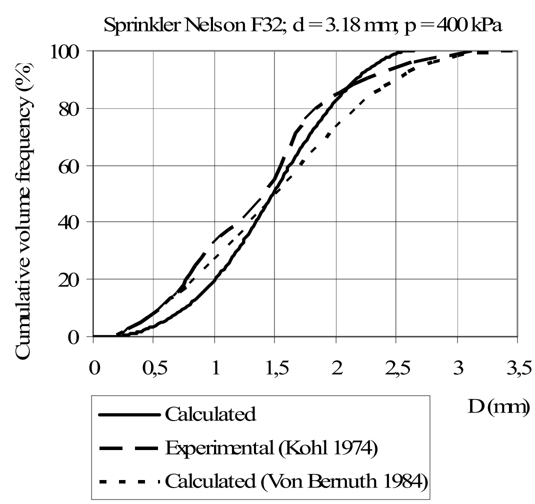

Figure-2. Comparison between calculated and experimental cumulative volume frequency vs. droplet size for the sprinkler Nelson F32 with 3.18-mm nozzle diameter at 400 kPa.

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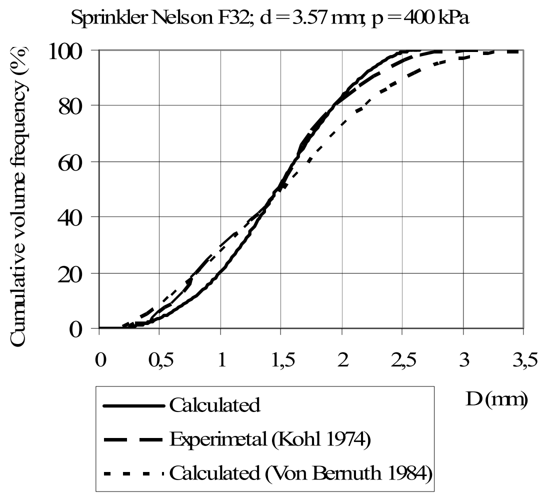

Figure-3. Comparison between calculated and experimental cumulative volume frequency vs. droplet size for the sprinkler Nelson F32 with 3.57-mm nozzle diameter at 400 kPa.

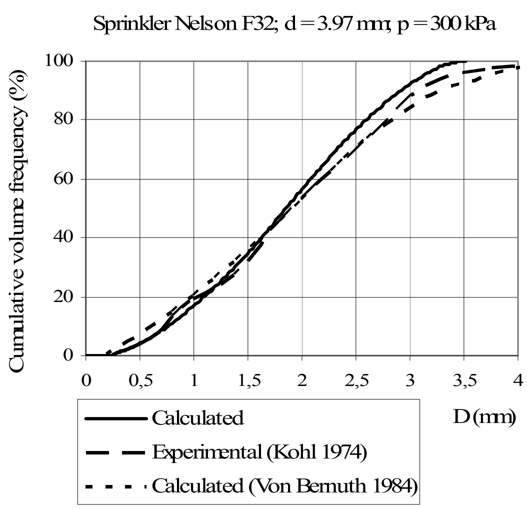

Figure-4. Comparison between calculated and experimental cumulative volume frequency vs. droplet size for the sprinkler Nelson F32 with 3.97-mm nozzle diameter at 300 kPa.

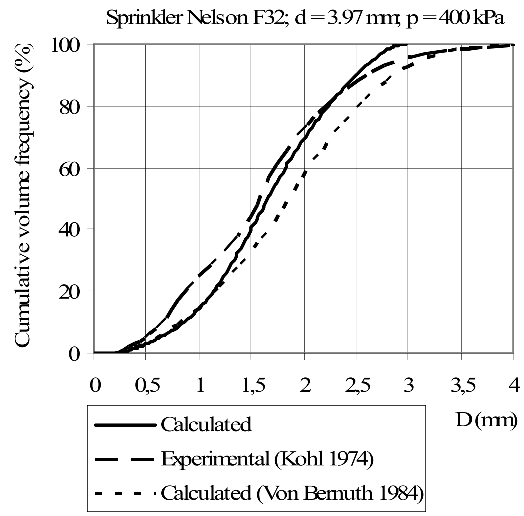

Figure-5. Comparison between calculated and experimental cumulative volume frequency vs. droplet size for the sprinkler Nelson F32 with 3.97-mm nozzle diameter at 400 kPa.

In Table-1 are shown the five Kolmogorov-Smirnov (KS) statistic d_{KS} values, obtained by comparing the Von Bernuth and Gilley calculated frequency curve and the Kohl experimental frequency curve: the average $d_{KS}$is good and equal to 0.140. Table 2 lists the five d_{KS}values resulting from the comparison between the frequency curve calculated by our model and the Kohl experimental frequency curve; here, the average d_{KS}*is* very good and equal to 0.076.

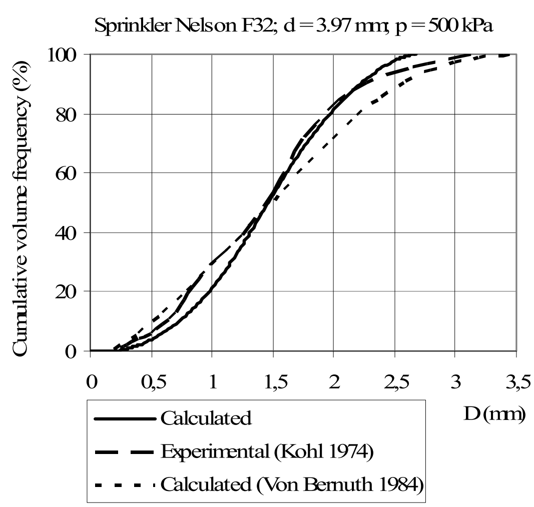

Figure-6. Comparison between calculated and experimental cumulative volume frequency vs. droplet size for the sprinkler Nelson F32 with 3.97-mm nozzle diameter at 500 kPa.

Table-1. Kolmogorov-Smirnov statistic d_{KS} of comparison between calculated (Von Bernuthand Gilley) and experimental (Kohl [11]) cumulative volume frequency for Nelson F32 sprinkler, with various nozzle diameters and pressures.

Sprinkler	Nozzle diameter (mm)	Pressure (kPa)	d_{KS}
Nelson F32	3.18	400	0.167
	3.57	400	0.121
	3.97	300	0.145
		400	0.133
		500	0.133
Average			0.140

For a further confirmation of the validity of the proposed procedure, the experimental data reported by Li [14] were also used, specifically the droplet-size spectra obtained by a sprinkler with a 6.5-mm nozzle diameter at three pressure values (245, 294 and 343 kPa). As Li [14] did not report the water distribution radial curves, we used the curves obtained in our laboratory tests of two sprinklers (Perazzi P22 and Komet R8) with 6-mm nozzle diameter at three operating pressures (250, 300 and 350 kPa) similar to those used by Li.

The pressure difference was only 2%, and hence negligible, as well as the difference among the nozzle diameters, given that the difference among the droplet-size spectra is very small. In fact, the *VMD* obtained by the Komet R8 sprinkler with a 6-mm nozzle diameter differed only 4.7% from the 7-mm nozzle diameter over the average of the three pressures. Therefore, it is reasonable to assume that this difference becomes about 2.4% on varying the nozzle diameter from 6 to 6.5 mm.

Table-2. Kolmogorov-Smirnov statistic d_{KS} of comparison between calculated and experimental (Kohl [11] and Li [14]) cumulative volume frequency for three sprinklers, with various nozzle diameters and pressures.

Sprinkler	Nozzle diameter (mm)	Pressure (kPa)	d_{KS}
Nelson F32	3.18	400	0.106
	3.57	400	0.066
	3.97	300	0.053
		400	0.100
		500	0.054
Average			0.076
Perazzi P22	6	250	0.106
		300	0.047
		350	0.173
		Average	0.109
Komet R8	6	250	0.072
		300	0.046
		350	0.220
		Average	0.113
Average			0.111

To confirm this, the *VMD* of the Nelson F32/F33 sprinkler with two different nozzle-diameter values (3.18 and 3.57 mm) can be examined; here, the *VMD* differed by only 0.9% at the 400 kPa pressure.

A comparison between the calculated frequency curves and the experimental curves of the Perazzi P22 sprinkler is shown in Figures 7, 8, and 9, for the three pressures, respectively. The obtained d_{KS} values are shown in Table-2, with a mean value of 0.109.

For the Komet R8 sprinkler the results are illustrated in Figures 10, 11 and 12, and the d_{KS} shows similar values, with a mean value of 0.113.

On examining Figures 9 and 12 more closely, it can be noted that the experimental curve obtained for the droplet-size spectrum by Li [14] at the higher pressure of 350 kPa shows a gibbosity not seen at the two lower pressures. This gibbosity is the cause of the higher d_{KS} values (0.173 for Figure 9 and 0.220 for Figure-12). If we consider only the experimental curves by Li at 250 and 300 kPa to be valid, the general mean value is 0.068, closer to the above-mentioned d_{KS} values obtained with the experimental data of Kohl [11].

CONCLUSIONS

The mathematical model showed in Part I [12] was submitted to validation using experimental data available in literature. At first, the droplet-size spectra, which were obtained by this mathematical model from the water distribution radial curves (indirect method), were compared with the experimental data by Kohl [11] to calculate the Kolmogorov-Smirnov statistic d_{KS}. The value of d_{KS} was 0.076, better than to d_{KS} = 0.140 obtained by use of a previous indirect method proposed by von Bernuth and Gilley [10].

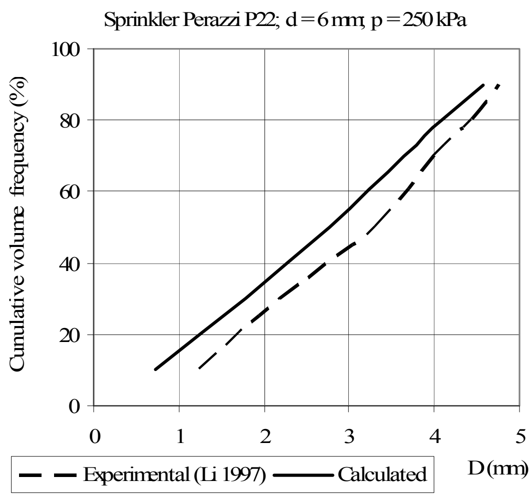

Figure-7. Comparison between calculated and experimental cumulative volume frequency vs. droplet size for the sprinkler Perazzi P22 with 6-mm nozzle diameter at 250 kPa.

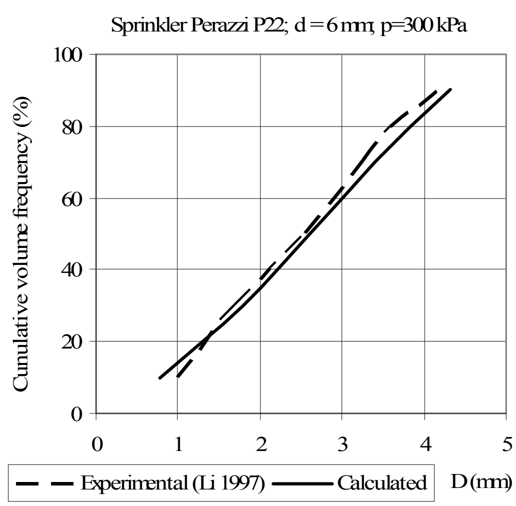

Figure-8. Comparison between calculated and experimental cumulative volume frequency vs. droplet size for the sprinkler Perazzi P22 with 6-mm nozzle diameter at 300 kPa.

A further validation of our method was done comparing the experimental values of the droplet-size spectra obtained by Li [14]; in this case, the water distribution radial curves required by the method were obtained from our laboratory tests by using similar, but not equal, nozzle diameter and pressures. These differences were the likely cause of the higher d_{KS} values (0.111 vs. 0.076), along with a gibbosity in the experimental cumulative-volume frequency curve by Li [14] at high pressure, not present in the frequency curves at lower pressures.

In conclusion, the method of von Bernuth and Gilley [10] was modified and improved in Part I [12] and here implemented in a spreadsheet for an easy and rapid use. This new indirect method can also be implemented in models for the design of sprinkler irrigation systems, useful to obtain a good uniformity of water distribution to optimize water use.

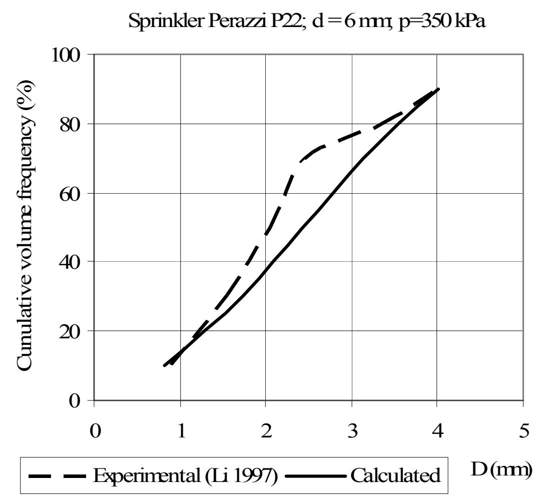

Figure-9. Comparison between calculated and experimental cumulative volume frequency vs. droplet size for the sprinkler Perazzi P22 with 6-mm nozzle diameter at 350 kPa.

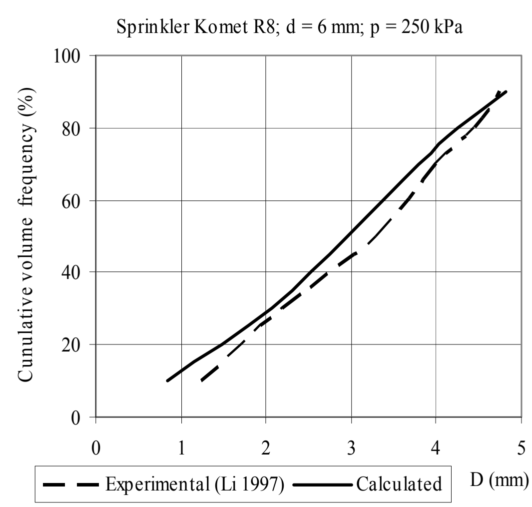

Figure-10. Comparison between calculated and experimental cumulative volume frequency vs. droplet size for the sprinkler Komet R8 with 6-mm nozzle diameter at 250 kPa.

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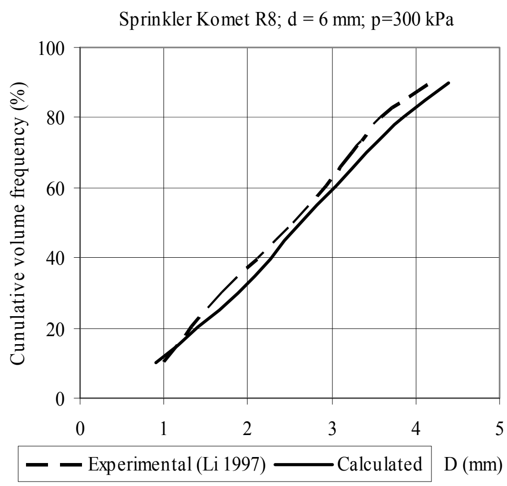

Figure-11. Comparison between calculated and experimental cumulative volume frequency vs. droplet size for the sprinkler Komet R8 with 6-mm nozzle diameter at 300 kPa.

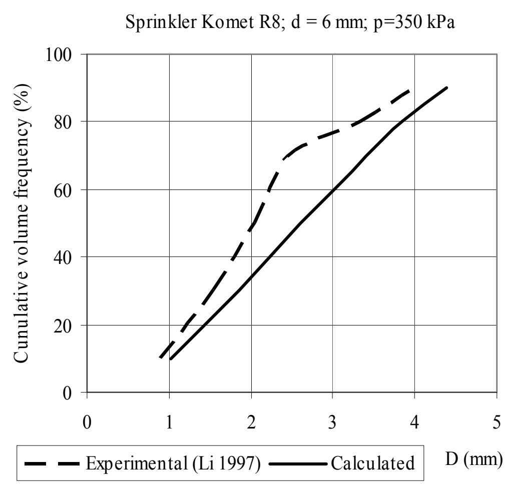

Figure-12. Comparison between calculated and experimental cumulative volume frequency vs. droplet size for the sprinkler Komet R8 with 6-mm nozzle diameter at 350 kPa.

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