TEKA Kom. Mot. Energ. Roln. – OL PAN, 2011, 11, 422–429

THE ASSESSMENT OF THE QUALITY OF SPRAY NOZZLES BASED ON THE SPRAY GEOMETRY

Cezary Wiśniewski

Warsaw University of Technology
Faculty of Civil Engineering, Mechanics and Petrochemistry
Department of Mechanical Systems Engineering and Automation
Address: Jachowicza 2/4, 09–402 Płock, Poland, e-mail: wis@pw.plock.pl

Summary. The transverse spray uniformity is very often used to assess spray quality. The value of the spray uniformity index (the coefficient of variation) is estimated on the basis of laboratory tests, carried out on the grooved table. The functional parameters of nozzles have direct influence on the value of this index. The differences between the actual and the nominal values of the parameters might have a significant influence on the quality of the spray during field works.

This study presents an analysis of the results of tests on the quality of flat fan nozzles used for fields spraying. The quality was evaluated on the basis of a statistical analysis of functional parameters characterizing the geometry of the spray stream. The obtained results allowed drawing conclusions and making comments on the influence of the spray nozzle quality on the spray process. The conclusions and remarks might be useful for the nozzle manufacturers.

Keywords: workmanship quality, nozzle, functional parameter, spray, quality evaluation

1. INTRODUCTION

Field crop spraying is one of the most frequently used agricultural and technical procedures particularly during vegetation of plants. Pesticides are poisons and can cause many dangers not only for the sprayer operator but also for outsiders and for other life forms in the environment [19]. Therefore, the use of minimal pesticide inputs and only when they are necessary is essential. The tests conducted in Poland and abroad are aimed at the minimization of the use of chemical preparations to the extent ensuring high quality and effectiveness of the procedure. The analyses of research work [4, 8, 19] showed that a lot of factors connected with the structure of sprayers, their functions and use, properties of the working liquid, atmospheric conditions and agricultural and technical conditions affect the quality and effectiveness of the procedure.

The spraying quality is evaluated on the basis of a non-uniform transverse distribution of the spray (the coefficient of variation), the values of which are calculated with the use of results of measurements performed on a grooved table (patternator). The spray uniformity index value is directly influenced by volumes and distribution of the liquid in grooves of the table depending on functional parameters of nozzles, including, the intensity of outflow of the technological liquid and the values of angles characterizing geometry of the spray stream. The relevance of the parameters is confirmed by the fact that for example the nominal values of the spray stream angle and liquid outflow rate are provided in nozzle type designations and spray nozzle selection instructions. The issue of evaluation of workmanship quality of the flat fan nozzles was tackled in several studies [21-24]. However, in order to supplement and update the evaluation, it is necessary to perform an analysis of quality, again considering the spray angle and the stream asymmetry angle in relation to the spray nozzle symmetry axis perpendicular to the sprayed area.

Due to the influence of special causes (assignable causes) and natural variability (chance causes of variation) of each production process [12], it is practically impossible to obtain spray nozzles with nominal value of the spray stream angle and ideal angle symmetry for the entire population. However, neither manufacturer information relating to spray nozzles used in agriculture nor any Polish standards provide admissible ranges of variability of the parameters, which do not affect the spray quality. Few manufacturers of industrial spray nozzles guarantee that the stream angle will not be changed by more than ±5° [5]. The tests [9] showed that the spray stream angle value, which is smaller than the nominal value, may lead to formation of liquid droplets greater than the assumed ones and, at the same time, worse coverage of plants with pesticides. Besides, as the computer simulations showed, a small asymmetry of the spray angle may (in some configurations of distribution of the spray nozzles on the spray boom) lead to a great value of the coefficient of variation for the boom [16].

2. LABORATORY TESTS

The laboratory tests were performed in the year 2003, on new, serial production flat fan nozzles used in spraying because of their great usability [1, 20]. For the selected type of spray nozzles and the liquid operating pressure of 0.3 MPa, the nominal values of the functional parameters are shown in Table 1.

Table 1. The nominal values of the functional parameters

Functional parameter	Nominal value
liquid outflow rate	$Q_{nom} = 2 \times 10^{-5}\ m^3\ s^{-1}$
spray stream angle	$\alpha_{nom} = 110°$
asymmetry angle (the angle between the stream symmetry axis and the nozzle symmetry axis)	$\beta_{nom} = 0°$

The tests were performed in accordance with recommendations presented in the standards [6, 7] and methodology of tests of tractor pressure sprayers [25]. The tests covered 300 flat fan nozzles mounted one by one on the spraying boom placed at the height of 0.5 m above the measuring table (patternator). The measurements were repeated three times in a row for each of the nozzles and for the same testing conditions. The tests involved measurements of intensity of the liquid outflow and video recording of the spray stream emitted by each of the nozzles. The detailed description of the test stand, the testing method and the preparation of the test data are presented in the studies [2, 3, 11].

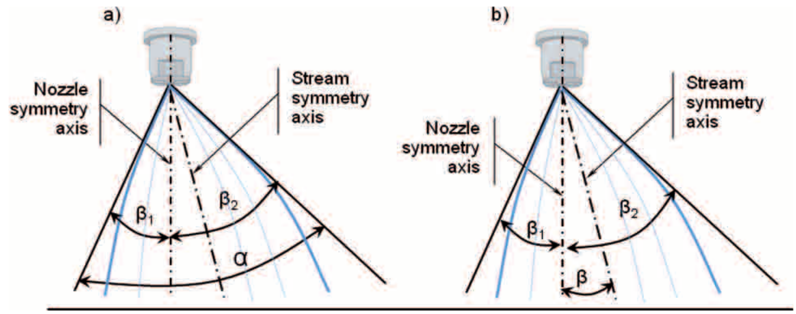

Fig. 1. Illustration of the method of angle determination in the spray stream: a) α - the liquid spray angle, where: $\alpha=\beta_1+\beta_2$, b) β - asymmetry angle, where: $\beta=0.5|\beta_2-\beta_1|$, β_1,β_2 – angles of the left and right parts of the spray stream in relation to the nozzle symmetry axis perpendicular to the sprayed surface [22]

The values of α and β angles characterizing the geometry of the spray stream (Fig. 1) were determined with the use of computer processing and statistical analysis of the recorded video images of the spray streams. The value of α angle was determined between the slant heights of the elliptical cone in the upper part of the stream before bending of the slant heights in the bottom part (Fig. 1a). This method of determination of liquid spray angle in the flat fan nozzle is commonly used by manufacturers and research centers [1]. The value of β angle has been calculated using the absolute value of the difference between β_1 and β_2 angles (Fig. 1b).

3. THE ANALYSIS OF TEST RESULTS

The data of the liquid spray angle and spray stream symmetry angle were subject to computer processing and statistical analysis. The analysis was aimed at the obtainment of assessment of the statistics describing trial empirical data and assessment of the compliance of the empirical data with the nominal values provided by manufacturers of nozzles. As a result of 300 trial evaluations of average spray angles and asymmetry, the basic statistical location and differentiation measures were determined (Table 2).

Table 2. The values of statistical location and differentiation measures of the empirical distribution for the liquid spray angle α and asymmetry angle β for flat fan nozzles [22]

Measure	Value	Measure	Value		
	Angle α	Angle β		Angle α	Angle β
Average	103.5°	0.96°	Maximum	107.5°	2.75°
Median	103.7°	0.84°	Minimum	97.1°	0.1°
Mode	104.3°	0.6°	Range	10.4°	2.65°
Variance	3.598	0.283	Lower quartile	102.15°	0.55°
Standard deviation	1.897°	0.535°	Upper quartile	104.95°	1.30°
Standard error	0.110°	0.031°	Coefficient of variation	1.83%	55.88%

When analyzing the results (Table 2) in terms of statistical location measures (e.g. average, median, mode, quartiles), it should be stated that:

- The average spray angle of the liquid emitted by the nozzle was 103.5º and was lower from the nominal value provided by the manufacturer (110º). The average symmetry angle value ($\beta_{śr}$=0.96º) also indicated that an average nozzle was characterized by asymmetry of the spray stream.
- Assuming that the tested nozzles represent a random collection of all nozzles of the type, the obtained average values should be interpreted with errors of 0.110º for angle α and 0.031º for angle β respectively.
- Half of the nozzles tested was characterized by liquid spray angles exceeding 103.7º and asymmetry angles exceeding 0.84° (median values).
- The dominant angle (mode value) in the spray nozzle test was α angle with the value of 104.3° and β angle with the value of 0.6°.
- Most typical nozzles used in the test were such nozzles, for which liquid spray angle values fell within the range of 102.15° and 104.95° (between the lower and upper quartile of α angle) and such nozzles, for which asymmetry angles fell within the range of 0.55° and 1,3° (between the lower and upper quartile of β angle).

When analyzing the calculated values (Table 2) of empirical characteristics of distribution (e.g. standard deviation, coefficient of variation), it may be stated that:

- The average differentiation (standard deviation) of the liquid spray angle was 1.897°, which, as expressed relatively (coefficient of variation), corresponds to approx. 1.83% of the arithmetic average. Such a low value of the variability coefficient proves a considerable homogeneity of nozzles in terms of deviation of the angle values from the average value.
- The average differentiation (standard deviation) of the asymmetry angle was 0.535°, which, as expressed relatively (coefficient of variation), corresponds to approx. 55.88% of the arithmetic average. Such a high value results from a considerable standard deviation (0.535°), which, in relation to the average value (0.96°) proves a considerable differentiation of the nozzles in terms of deviation of the angle values from the average value.

The above-mentioned observations are illustrated in a graphic presentation of the distribution series composed of the analyzed data (Fig. 2 and 3).

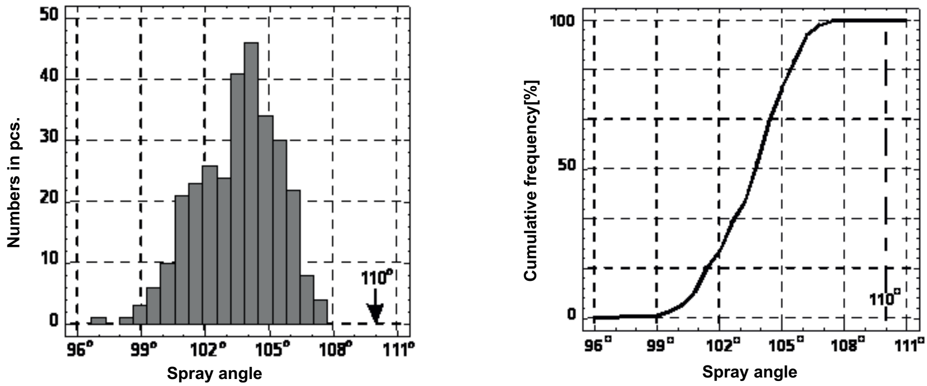

Fig. 2. A histogram of numbers and a cumulative frequency curve for the testing of data of the liquid spray angle (α) with indicated level of the nominal value 110° [22]

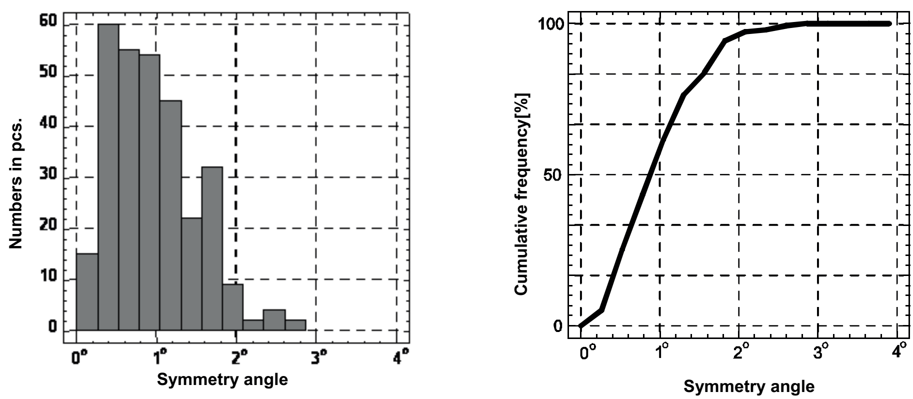

Fig. 3. A histogram of numbers and a cumulative frequency curve for the esting of data of the liquid stream asymmetry angle (β)

By treating the tested sample of nozzles as representative for the entire population of nozzles of the type and taking into account large numbers of the sample (300 elements), it may be assumed that the tested nozzles are characterized by the liquid spray angle value lower than that indicated by the manufacturer. This assumption is justified because 100% of the nozzles tested were characterized by liquid spray angle values lower than the nominal value of 110°.

The difference observed between the average value of the sample ($\beta_{śr}$=0.96°) and the assumed nominal value of the liquid stream asymmetry angle (β_{nom} = 0°) does not require any verification in terms of statistical relevance due to the fact that 100% of the values in the large samples composed of 300 elements were greater than 0°.

4. CONCLUSIONS

The conducted analysis aimed at the evaluation of the workmanship of new serial production flat fan nozzles. The obtained results and conclusions can be useful for the nozzle manufacturers and to formulating standards and quality requirements.

By adopting a definition of the quality quoted in the standard [17] as "degree, to which a set of inherent characteristics (...) fulfils requirements (...)", it may be stated that the considered functional parameters constitute the characteristics (inherent characteristics) of nozzles affecting correct spraying procedures (in accordance with the equipment specified in the standards, for example). An inadequate quality level of nozzles may result in a failure to fulfill the user's expectations related to the effectiveness and costs of the procedure or may cause negative impact on the natural environment.

The statistical test performed on a large randomly collected sample of flat fan nozzles enabled an evaluation of the statistical values characterizing the population of nozzles in terms of some functional parameters. In characterizing the population of nozzles, attention should be paid to the following main conclusions:

- Average values of α and β angles differ considerably (in terms of statistics) from the values indicated by the manufacturer. The difference shows that the production process of nozzles was out of control and that the influence of assignable causes resulted in the movement of the process mean (desirable nominal value) to the undesirable value.
- The nozzles were characterized by a high homogeneity in terms of deviation of angle α from the average value (1.83%) and showed great differentiation for angle β (55.9%). The great value of the coefficient of variation for angle β shows that the production process was unstable and the dispersion of the angle β values in the population of nozzles was considerable.
- Due to the confirmed deviation of the values of α and β angles from the nominal values, it would be purposeful for manufacturers to indicate admissible values of the deviations in order to provide unambiguous evaluation of the quality of nozzles and eliminate nozzles that do not comply with the manufacturer specifications.

The above-mentioned comments enable an evaluation quality of flat fan nozzles, although the evaluation is not unambiguous and it depends on an adopted criterion. The unambiguity of the evaluation results particularly from the absence of available data relating to tolerance ranges for α and β angles that could guarantee good quality of spraying. As regards the tolerance ranges for the angles, one may consider Shewhart's criteria [18], however, the adoption of this approach would require a verification in the form of additional laboratory tests and simulation analyses.

From the practical point of view, the quality of the evaluated spraying was based on a non-uniform transverse distribution of the spray as determined for the spraying boom, and depended, to a great extent, on the order in which nozzles are mounted in the boom – a fact to which the study [16] referred. This results from non-uniform "overlapping" of asymmetrical cones of the spray streams across the width of the spraying boom. Additionally, in the case of the liquid spray angle, a considerable difference between the actual value and the nominal value of the angle may lead to formation of droplets even greater than the assumed ones and, at the same time decrease of the degree of coverage of crops with a pesticide. Besides, the value of the angle, which is lower than the nominal value of the angle, will lead to a decrease of the transverse range of the spray streams for the spraying boom located at the height recommended by the manufacturer in the manual.

Considering the above-mentioned comments, it may be stated that taking into account the statistical analysis of the liquid spray angle values and stream asymmetry only as well as conclusions resulting from the analysis, the quality of workmanship of the nozzles (compliance with the nominal values) may be evaluated unequivocally as unsatisfactory. However, there is still an open issue of evaluation of the influence of low quality workmanship of nozzles on the quality of spraying, which may be determined upon testing of the relation between the indicator of the spraying quality and variability of functional parameters of the nozzles mounted in the spraying boom.

Future trend in the studies should involve such tests that would allow detecting the causes of deviation of the functional parameter values of nozzles from the nominal values. The causes may result from inappropriate quality of production or inappropriate structure of the nozzles causing high sensitivity of functional parameters to insignificant random changes in the workmanship quality. The tests may consider an analysis of the internal structure of a nozzle, including the influence of accuracy of the surfaces inside the nozzle chambers and channels or shaping of the chambers and channels for the purposes of variability of the functional parameters.

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OCENA JAKOŚCI ROZPYLACZY NA PODSTAWIE BADANIA GEOMETRII STRUGI OPRYSKU

Streszczenie. Jakość oprysku bardzo często oceniana jest na podstawie jego poprzecznej równomierności. Wartość wskaźnika nierównomierności oprysku (współczynnika zmienności) szacowana jest metodą badań przeprowadzanych w warunkach laboratoryjnych na stole rowkowym. Na wartość tego wskaźnika bezpośredni wpływ mają wartości parametrów funkcjonalne badanych rozpylaczy. Różnice pomiędzy wartościami rzeczywistymi i nominalnymi tych parametrów mogą w istotny sposób wpływać na jakość oprysku podczas prac polowych.

W pracy przedstawiono ocenę wyników badań jakości wykonania rozpylaczy płaskostrumieniowych, stosowanych w opryskiwaczach polowych. Oceny dokonano na podstawie analizy statystycznej wartości parametrów funkcjonalnych charakteryzujących geometrię strugi oprysku. Na podstawie uzyskanych wyników sformułowano wnioski dotyczące jakości wykonania rozpylaczy oraz uwagi związane z wpływem tej jakości na jakość oprysku. Wnioski i uwagi mogą być przydatne dla producentów rozpylaczy rolniczych.

Słowa kluczowe: jakość wykonania, rozpylacz, parametr funkcjonalny, oprysk, ocena jakości