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EVALUATION OF FLAT FAN NOZZLES OPERATING PARAMETERS UNDER CONDITIONS OF ACCELERATED BOUNDARY AND DESTRUCTIVE WEAR

Stanisław Parafiniuk[a], Marek Milanowski[a*]; Anna Krawczuk[a], Józef Sawa[b], Alaa Kamel Subr[c]

[a] Department of Machinery Exploitation and Management of Production Processes, University of Life Sciences in Lublin,
[b] East European State Higher School in Przemyśl,
[c] Department of Agricultural Machines and Equipment, College of Agriculture, University of Baghdad, Baghdad, Iraq

Corresponding author: e-mail: marek.milanowski@up.lublin.pl

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ABSTRACT

Two tests were carried out to measure the standard flat fan nozzles wear during a specific period of an accelerated wear procedure. The first test aimed at getting 10% increase in the flow rate compared to the nominal flow rate, which is the threshold to replace the nozzles according to the nozzles testing standards. The second test was to wear the nozzles intensively (100 hours of accelerated wear), which represents the use of nozzles beyond the allowed threshold. The results showed that the flow rate reached 1.31 $l \cdot min^{-1}$ (equal to 10% increase) for the tested nozzles after 35 hours of the wear test. For the second test, the 10% increase of the flow rate was reached after approximately 30 hours. The wear rate reached 27.5% at the end of the test and this is 2.7 times more than the standardized threshold.

Introduction

It is essential to be aware of the harmful effect of agrochemical products and the application procedure of these products; however, they are still necessary in modern agriculture. The European and national authorities, Plant Protection Product (PPP) producers and other organizations initiate actions to secure the use of PPP, for example to protect the sprayer operator, the consumer and the environment. The PPP registration (or its withdrawal), monitoring, program of the PPP use reduction, integrated pest management, code of good practices, user training and other actions, were initiated in order to get better PPP use management (Huyghebaert et al., 2004). The safety standards aim to ensure the basic levels of safety, even if they oppose the direct economic considerations. These standards have two aspects. The first one is to describe the equipment minimum requirements that need to be approved or certified and it is usually used for an official certification system. The second aspect is to provide a standard that can describe the level of technology desired to induce improvements in the equipment quality (Friedrich, 2001).

As previously stated, there is a necessity to use pesticide in the crop production process in spite of its risk and impact on the environment. However, this use was restricted and regulated with different national and international standards. Those standards and regulations are aiming to reduce the applied quantity and risk of pesticide use.

Nozzles for PPP application are widely used by farmers. For that reason, Directive 2009/128/EC and EN 13790-1:2003 or EN ISO 16122-2:2015 define specific requirements for this important element of the sprayer. Nozzles are the element for direct dispensing of pesticides. Parameters of their work have a great impact on the technical, biological and economical efficacy of the treatment, on the human health and the environment. It is believed that the nozzles ensure the sustainable use of pesticides. Exploitation process, deformation of the nozzles' tips occurs causing an increase in the flow rate of the spray, but this has the impact on changes that shape the parameters of the spray formed by the nozzle.

According to previous studies of different authors, the nozzles wear could affect the nozzles and the spray. The parameters affected are: dimensions of the nozzle tip, flow rate, spray distribution, spray angle, drop size and its volumetric distribution. The main goal of initiating any wear test of nozzles is to investigate the change in the wear rate or the wear severity during specific time. In this work, it was assumed that the flow rate of liquid from the flat fan nozzles is a basic parameter to indicate the working life (within the limits of the testing standards) of the nozzles.

Materials and methods

Standard flat fan nozzles widely used in agriculture (TeeJet XR 110/03 VP Spraying Systems Co.) were used in all the tests. Table 1 shows detailed information on those nozzles.

Table 1.
Standard flat fan nozzles (TeeJet XR 110/03 VP) features

Producer	Spraying Systems Co.	TeeJet nozzles
Name	Extended Range Flat Fan, XR 110/03 VP, VisiFlo® color-coding.	
Nominal flow rate	1.18 $l \cdot min^{-1}$ (at 3 bar pressure)	
Working pressure range	1.0-4.0 bar	
Spray angle	110º	
Material	Polymer	
Drop size (VMD)	Medium-fine (depending on pressure)	
Application rate $l \cdot ha^{-1}$	With 4.0 $km \cdot h^{-1}$ travel speed	354
(with 3.0 bar pressure	With 5.0 $km \cdot h^{-1}$ travel speed	283
and 50 cm nozzles spacing)	With 6.0 $km \cdot h^{-1}$ travel speed	236

Before initiating the tests, the characteristics of new nozzles spray (just after purchasing) was determined. All the tested nozzles had initial flow rates within ± 5% (according to ASAE S471, 1999) of the mean flow rate of all nozzles. Two groups of 24 nozzles were used in the wear period experiment. All nozzles were numbered individually from 1 to 24. Nozzles from 1 to 12 were subjected to accelerated wear test, while nozzles from 12 to 24 were considered to be "new nozzles".

Changes in the nozzle dimensions were measured using Keyence VHX-2000 digital microscope, which consisted of exchangeable lens (magnification ranged from 20-fold to 200-fold), camera (resolution of 1600 x 1200 pixels), stand and a controller unit. The system has sophisticated 2D and 3D measurement software able to measure the area, dimensions and volume by depth composition concept. This is done with the help of different image quality improvement tools like HDR imaging, glare removal, light shifting and image stitching (Narra et al., 2014). Measured dimensions were: minimum (short) and maximum (long) diameters in µm; the orifice perimeter in µm and the orifice area in μm^2.

During their use, the spraying nozzles are subjected to physical, chemical and/or thermal wear. This study focuses only on the first type of wear (physical wear), which happens due to the abrasive effect of the atomized spray particles (erosion wear). To investigate the changes of the spray characteristics during the life of nozzles, the accelerated wear test was applied. One part of the test (the standardized accelerated wear test) was realized according to the procedure for measuring the wear rate of the sprayer nozzles standards from ASAE S471 and ISO 5682-1:1996. This standard could be applied to hydraulic powered nozzles with the flow rate up to 3.0 $l \cdot min^{-1}$. ISO 5682-1:1996 mentioned that the test should be stopped when the percentage flow rate increase reaches 15% or when the wear time reaches 100 hours.

The laboratory experiment consisted of two tests:

1 - The standardized accelerated wear test: by wearing a group of nozzles until they reach 10% increase in flow rate of their nominal flow rate (specified by the manufacturer). This group of nozzles was called “the worn nozzles”.

2 - The intensive accelerated wear test: by damaging another group of nozzles (subject them to 100 hours of accelerated wear). This group of nozzles was called “the damaged nozzles”. The word “damaged” refers to the nozzles damage due to the intensive wear (long exploitation) of nozzles, not to accidental or chemical damage for example.

The nozzles were subjected to different wear time intervals and the flow rate were measured at every specific period. Besides, the group of nozzles was not subjected to the accelerated wear test and this group was called “the new nozzles”. Table 2 shows more information about the standardized and accelerated wear tests.

Table 2.
Parameters of the standardized and accelerated wear tests for nozzles

Specification	The standardized accelerated wear test	The intensive accelerated wear test
Number of nozzles	24	24
Number of nozzles subjected to accelerated wear test	12	12
Test pressure	3 bar	4 bar
Duration of the test	35 hours	100 hours
Flow rate measurement intervals	Every 5 hours of wear	After 10, 20, 40, 60, 80, 100 hours of wear
Spray distribution and drop size measurement	Different intervals	Different intervals
Nozzles warm-up before the test	Yes	Yes

One of the functions of a nozzle is to determine the quantity of applied pesticide, and it is expressed in liters per minute. The flow rate was measured by using a specific measuring device from ITEQ (detailed description and calibration parameters are mentioned by Huyghebaert, 2015). The measurements are registered automatically by equipment computer software.

As mentioned before, the flow rate was measured after specific intervals of wear. The nozzles were dismounted from the wear tank, cleaned with clean water and by compressed air. The measurements were made at different pressure and in three replicates. The measurements were done when the pressure and the readings on the device monitor were stabilized.

Results

As other studies indicate, these changes can be observed by measuring the dimensions of the nozzle orifice during the test (Krishnan et al., 2004; Krause et al., 2003; Sztachó-Pekáry, 2005). However, this parameter (ozzle orifice diameter) appears to be not practical when dealing with the inspection of sprayers, which is required by the Directive 2009/128/EC for the sustainable use of pesticide. This impracticality is mainly caused by the fact that during the test a precise instrument is needed to detect and measure the changes in the dimensions of the nozzle tip, and a long time needed for the measurement.

The minor and major axes (minimum and maximum diameters) of the elliptical orifice of nozzles were numerically higher for the damaged and worn nozzles than those for the new nozzles (Tab. 3). The same observation concerned the area of the nozzle tip, with an increased number of worn and damaged nozzles – by 2.2% and 8.1% respectively, as compared to new nozzles. However, the perimeter for the worn nozzles was smaller than that in the new nozzles. This is probably, because the new nozzles have winding curves at the far end of the major axis, which they wore out during the wear test. The damaged nozzles have the largest dimensions and this was because of the friction of their orifices during the test. Krause et al., 2003 attributed the wear of nozzle orifice to the suspended particles in the pesticide liquid when they pass with high speed through the nozzle tip.

Table 3.
Dimensions of new, worn and damaged nozzles

Dimension measurement	New nozzles	Worn nozzles	Damaged nozzles
Min. diameter, (μm)	451	457	476
Max. diameter, (μm)	2090	2136	2176
Perimeter, (μm)	5105	5020	5423
Area, (μm^2)	818805	837040	891360

The tested nozzles received this assumpted 10% threshold after 35 hours of the wear test ($1.31\ l \cdot min^{-1}$). The flow rate at 3.0 bar pressure was measured in 5-hour intervals (Tab. 4) for each of the 12 nozzles (with three replicates) and then average values were calculated. The standard deviation for the 12 nozzles sample before and after warm up was within the allowed limit according to ASAE S471 to initiate the test, which indicates homogeneity of the test sample.

Table 4.
Standardized wear test, wear rate (%), flow rate (l·min^{-1}) measured during different wear periods using 3.0 bar pressure

Flow rate after different wear periods, l·min^{-1}									
			Duration of wear, hours						
		After warm-up	05	10	15	20	25	30	35
Average of flow rate, (l·min^{-1})	1.21	1.21	1.22	1.23	1.26	1.27	1.27	1.29	1.31
SD	0.009	0.009	0.012	0.012	0.011	0,010	0.010	0.012	0.012
Average wear rate (%)	2.3	2.3	3.1	4.2	6.6	7.2	7.9	9.5	10.6
Nominal flow rate +10%	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30

Warming up the nozzles for 10 hours by circulating only water through the nozzles did not produce any significant (p-value = <.0001) change in the averaged flow rate comparing with after warm-up and after five hours of wear. However, the wear rate before warm-up was 2.3% and it was the same after the warm-up. This was because the measured flow rate for the new nozzles (1.21 l·min^{-1}) was higher than the nominal flow rate (1.18 l·min^{-1}) even though the nozzles were new. The results indicated a progressive increase in the wear rate during the test intervals. The first significant change in the flow rate between two progressive periods of wear happened after 15 hours of wear comparing with 10-hour wear. There was not significant difference in the flow rate when the wear periods increased from 15 to 20 hours of wear. The same situation happened after 20 hours of wear comparing with 25 hours of wear. A significant increase occurred after 30 hours of wear (9.3 %) and also another significant increase happened after 35 hours of wear (11.0 %).

Figure 1 shows the effect of 35 hours of wear on the measured flow rate and also the wear rates during the wear periods. When measurements were done at 3.0 bars, and the line at 10% wear rate relates to the allowed increase of the nozzle flowrate (for field crop sprayers).

The 100-hour accelerated wear test (Table 5 and Figure 2) lasted longer than the standardized wear test. The results of the flow rate of 12 nozzles at pressure of 3 bar for different periods of wear are presented. Again, the standard deviation after warm-up was within the allowed limitset by ASAE S471. However, the standard deviation gradually increased during the wear intervals, which means that certain nozzles wore with different rate than others.

The results indicate the increase in the flow rate for all time intervals (wear test durations). This increase was faster in the first wear intervals, and next (intervals from 60-100 hours of wear periods) it slowed down. The averaged wear rate numerically declined after 10 hours of wear comparing to the after warm-up value, and after this, it started to increase gradually. This was observed also by Huyghebaert, 2015, who reported a decrease in flow rate during the first hour of wear, suggesting that this behavior refers to plastic nozzles. The same finding was observed by Duvnjak et al., 2009.

The 10 percent increase threshold of the flow rate, which was set by the international standards (for field crop sprayers), was reached after approximately 30 hours. At the end of the test, the wear rate was 27.5% and this is 2.7 times more than the standardized threshold.

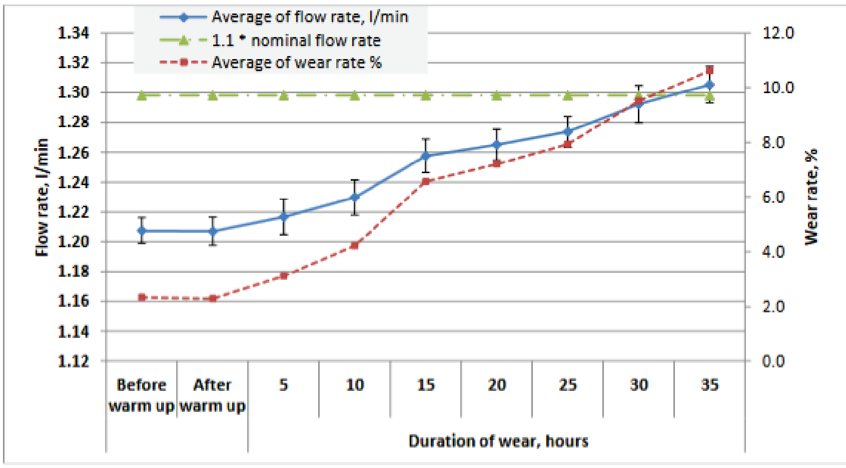

Figure 1. Nozzles wear rate % during different wear intervals and flow rate with 3.0 bar pressure

Table 5.
Intensive wear test, wear rate (%) and flow rate ($l{\cdot}min^{-1}$) for new and damaged nozzles with 3 bar pressure

Specification	Flow rate during different wear periods, ($l{\cdot}min^{-1}$)						
	Duration of wear test, (hours)						
Nozzle No.	After warm up	10	20	40	60	80	100
Average of flow rate	1.20	1.20	1.27	1.33	1.42	1.46	1.51
SD	0.013	0.015	0.015	0.015	0.032	0.024	0.022
Average of wear rate (%)	2.0	1.4	7.6	13.1	20.1	23.5	27.5
Nominal flow rate +10%	1.30	1.30	1.30	1.30	1.30	1.30	1.30

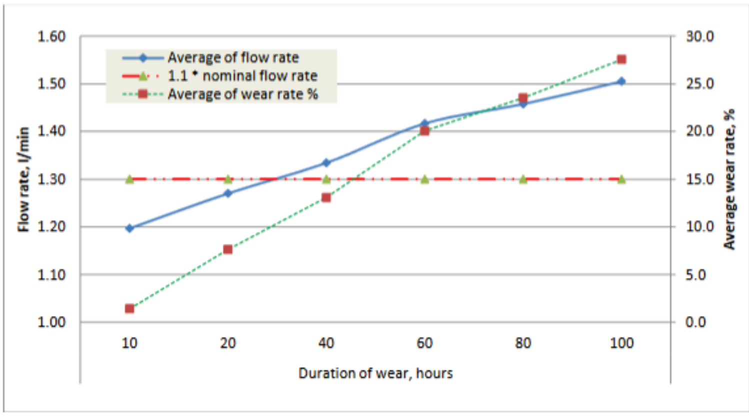

Figure 2. Nozzles flow rate and wear rate during different wear intervals measured at 3 bar pressure

Decreasing the working pressure is one option for the sprayer operator to compensate the increase of the flow rate (due to the wear out of the nozzles) besides increasing the forward speed of the sprayer. The results for the flow rate measurements (Fig. 3 and Tab. 6) with different working pressure indicate the identical percentage increase in flow rate for new and damaged nozzles when changing pressure to a higher value. The working pressure (1.0, 1.5, 2.0, 2.5, 3.0, 4.0 bar) was chosen according to recommendations given in the producer's catalogue for the acceptable application of pesticide. The highest percent increase in the flow rate was observed during raising pressure from 1.0 to 1.5 bars for both new and damaged nozzles. While the lowest percent increase was observed when raising pressure from 2.5 to 3.0 bars and again for both new and damaged nozzles. When measuring the flow rate at 1.0; 1.5; 2.0; 2.5; 3.0; 4.0 bar the differences in the flow rate between new and damaged nozzles were: 0.19; 0.23; 0.27; 0.30; 0.32 and 0.37 $l \cdot min^{-1}$, respectively.

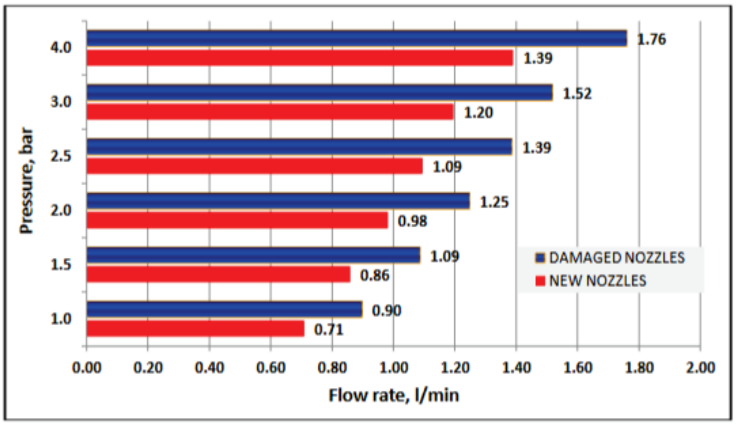

Figure 3. Effect of different operating pressures on the flow rate for new and damaged nozzles

The results from Table 6 indicate no influence of the nozzles wear on the relation between the percentage increases of the flow rate due to changing the working pressure. This will add more difficulty for the task of finding or discovering the wear of the nozzles.

Table 6.
Changing the working pressure effect on the percentage increase in flow rate

Specification	Percentage increase in flow rate, (%)				
Changes in working pressure--->	1---> 1.5 bar	1.5---> 2 bar	2--->2.5 bar	2.5--->3 bar	3--->4 bar
Damaged nozzles	21.1	14.9	11.1	9.5	16.0
New nozzles	21.1	14.3	11.5	9.3	16.2

The allowable limit of 10% increase in the flow rate was tested at a pressure of 3 bar. However, Table 7 also shows the limits for each working pressure and compares them with the nominal flow rate.

Table 7.
Values of the flow rate for each working pressure after 10% limits of increase

Specification	Working pressure, (bar)					
	1.0	1.5	2.0	2.5	3.0	4.0
Nominal flow rate, ($l \cdot min^{-1}$)	0.68	0.83	0.96	1.08	1.18	1.36
10% increase in flow rate	0.75	0.91	1.06	1.19	1.30	1.50

Summary

Parameters used to characterize the spray generated by the nozzles are: the flow rate, spray distribution, and angle, drop size, etc. Monitoring and controlling the agricultural nozzles is important because of the liquid sprayed by those nozzles, which is generally PPP (in case of nozzles used for PPP application). During the progress of the nozzle work life, the nozzle orifice dimensions and the characteristics of the spray will be subjected to changes. Different international, regional and national standards and regulations are established to test and control the quality of the agricultural nozzles. Those standards suggested periodical inspections and allowed limits for some parameters, which are supposed to be affected by the nozzles wear. The flow rate measurement it is most consistent and accurate parameter to indicate the working life of the agricultural nozzle. According to Directive 2009/128/EC, ISO 16122-2:2015, the inspection of nozzles was linked to the flow rate and transverse distribution measurements. The findings of this study suggest that the changes in the flow rate start to increase linearly even from the early stages of the nozzle wear, giving the sprayer inspector the ability to produce clear and trusted decision concerning the acceptance or rejection of the inspected nozzles.

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OCENA PARAMETRÓW PRACY ROZPYLACZY PŁASKOSTRUMIENIOWYCH W WARUNKACH PRZYSPIESZONEGO ZUŻYCIA GRANICZNEGO I NISZCZĄCEGO

Streszczenie. W pracy zaprezentowano pomiary stopienia zużycia rozpylaczy płaskostrumieniowych standardowych po wykonaniu dwóch testów z wykorzystaniem procedur przyspieszonego zużycia. Pierwszy test miał na celu uzyskanie wzrostu natężenia przepływu o 10% w porównaniu do nominalnego natężenia przepływu, które stanowi normę do wymiany rozpylacza rolniczego zgodnie ze standardami testowania rozpylaczy. Podczas drugiego testu następowało intensywne zużycie dysz (100 godzin przyspieszonego zużycia), które powodowało zużycie dysz powyżej dopuszczalnej normy. Wyniki wykazały, że natężenie przepływu wyniosło 1,31 l/min (co stanowi wzrost o 10% natężenia przepływu) dla testowanych dysz po 35 godzinach w pierwszym teście zużycia. W drugim teście wzrost natężenia przypływu o 10% osiągnięto po około 30 godzinach. Wskaźnik zużycia po zakończeniu drugiego testu osiągnął wartość 27,5% i jest 2,75 razy większy niż dopuszczalna norma zużycia. Wyniki badań sugerują, że zmiany natężenia przepływu zaczynają wzrastać liniowo nawet od wczesnego etapu zużycia rozpylaczy, dając możliwość uzyskania precyzyjnej decyzji dotyczącej przyjęcia lub odrzucenia użytkowanych rozpylaczy.

Słowa kluczowe: rozpylacze płaskostrumieniowe; zużycie rozpylaczy; natężenie przepływu; zrównoważone stosowanie pestycydów

Identification data Authors:

Stanisław Parafiniuk	*https://orcid.org//0000-0002-8566-6527*
Marek Milanowski	*https://orcid.org/0000-0003-3367-7942*
Anna Krawczuk	*https://orcid.org/0000-0001-6227-7740*
Józef Sawa	*https://orcid.org/0000-0002-4455-5724*
Alaa Kamel Subr	*https://orcid.org/0000-0001-5529-9773*