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Operational Performance of JA-1 and JA-2 Hydraulic Nozzles Used in Hydropneumatic Sprayers

Desempeño operacional de las boquillas hidráulicas JA-1 y JA-2 utilizadas en pulverizadores hidroneumáticos

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ABSTRACT: Hydraulic spray nozzles are very important in hydropneumatic sprayers and are primarily responsible for dividing the liquid into droplets. This study evaluates the operational performance of two types of conical jet nozzles at four operating pressures. The nozzle flow rate and the influence of pressure on the discharge coefficient were evaluated. Spray nozzles JA-1 and JA-2 showed flow rates statistically equal to those provided by the manufacturer. The discharge coefficient of both nozzle sets was lower than the value proposed for turbulent flow orifices, with lower values for the series with the smaller orifice diameter. Volumetric distribution varies depending on the flow rate and nominal pressure. To establish operating parameters for spraying equipment, it is essential to understand the characteristics of the spray nozzles and their operating status.

Keywords: Conical Jet, Application Technology, Pesticides, Flow Rate.

RESUMEN: Las boquillas aspersoras hidráulicas son muy importantes en los pulverizadores hidroneumáticos y son las principales encargadas de dividir el líquido en gotas. Este trabajo tiene como objetivo estudiar el desempeño operativo de dos tipos de boquillas de chorro cónico, a cuatro presiones de trabajo. Se evaluaron el caudal de la tobera y la influencia de la presión en el coeficiente de descarga. Las boquillas aspersoras JA-1 y JA-2 mostraron caudales, estadísticamente iguales a los proporcionados por el fabricante. El coeficiente de descarga de los dos juegos de toberas fue inferior al valor propuesto para los orificios de flujo turbulento, siendo valores inferiores para la serie con menor diámetro de orificio. La distribución volumétrica varía en dependencia del caudal y presión nominal Para establecer parámetros de trabajo en los equipos de pulverización, es fundamental conocer las características de las boquillas pulverizadoras y su estado de funcionamiento.

Palabras clave: chorro cónico, tecnología de aplicación, pesticidas, caudal.

INTRODUCTION

Pesticide application technology has experienced significant advances in recent decades, driven by the need to optimize agronomic efficiency and reduce environmental impact (Rodrigues, 2005). However, critical challenges persist, such as inefficient pesticide application, which can result in inadequate deposition of the active ingredient-either through excess, increasing the risk of contamination, or through insufficient application, compromising pest control (Ferguson *et al.*, 2018). This problem largely stems from an unbalanced approach that prioritizes chemical selection over application technique, despite the latter determining up to 70% of treatment success (Garcerá *et al.*, 2017). In a global context demanding sustainability, with stricter regulations (e.g. European Union Directive 2019/782 (2019) and consumers demanding food with less residue, precision spraying has become indispensable. Here, droplet size emerges as a key factor: it directly influences leaf coverage, drift and product retention (Butler *et al.*, 2020). Technologies such as sensor-assisted spraying and anti-drift nozzles (e.g. air-induced) seek to optimize this parameter, but their effectiveness depends on rigorous, evidence-based calibration (Grella *et al.*, 2017). Hydraulic nozzles, widely used in conventional agriculture (85% of the equipment, according to FAO (2021), are the central component that defines the droplet spectrum (Rodrigues, 2005). Recent studies show that their performance is determined by: geometric characteristics (spray angle, type of induced turbulence); operating conditions (pressure, flow rate, broth formulation); environmental factors (wind, relative humidity) (Nuyttens *et al.*, 2023).

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In particular, hollow cone nozzles-recommended for insecticides-generate a heterogeneous distribution profile, with greater deposition at the periphery of the jet (Cunha *et al.*, 2023). However, their efficiency critically depends on maintaining optimal pressures (200-1000 kPa) and monitoring the coefficient of discharge (Cd), whose ideal value (0.611) ensures turbulent flow and uniformity (ISO 25358, 2023). This work evaluates the operational performance of hollow cone nozzles under different pressures, using traceable methodologies ASABE S572.1. (2023) to generate parameters that optimize: target deposition (≥30 impacts/cm² on leaflets, according to EPA criteria); drift minimization (<10% of droplets <150 µm in wind conditions ≤10 km/h); economic efficiency (up to 20% reduction in input use; data from Foquino *et al.* (2023).The integration of these technical advances with sustainable agronomic practices not only improves productivity but also aligns agriculture with the Sustainable Development Goals (SDGs 12 and 15), reducing risks for operators and ecosystems.

MATERIALS AND METHODS

The tests were conducted in the Agricultural Mechanization Laboratory of the Department of Agricultural Engineering at the Federal University of Viçosa, using a test bench built in accordance with ISO 5682/1 (1986), designed to determine the flow rate and volumetric distribution of nozzles (Rodrigues *et al.*, 2004). Hydraulic pressure was generated by a piston pump with a maximum flow rate of 20 L min-1 and a maximum pressure of 500 kPa, driven by a 220 V electric motor with a power equivalent to 2.2 kW. The bench is equipped with a pressure regulation and fluid filtration system. Pressure was measured with a calibrated Famagras pressure gauge, with a nominal capacity of 1578.6 kPa and a resolution of 19.73 kPa (Rodrigues et al., 2004). Calibration was performed using a standard mass system to obtain the relationship between indicated and actual pressure. The system consisted of a PH-80 hydraulic pump and an Enerpac RCH-120 hollow-piston hydraulic cylinder. This system was mounted on a reaction structure equipped with a metal rod to load masses in increments of approximately 10 kg. Three loads of approximately 205 kg were applied to verify the repeatability of the readings. This allowed the calibration curve of the pressure gauge under study to be obtained. The calibrated pressure gauge was mounted on the test bench, where the spray nozzles were tested. Conical ceramic nozzles, model JA-1 (1 mm diameter) and JA-2 (1.3 mm diameter), produced by Jacto, were used. These nozzles are recommended for operating at pressures of 414 to 1448 kPa in hydropneumatic sprayers. The flow characteristics of the nozzles to be evaluated are shown in Table 1.

For the flow study, 14 nozzles from the JA-1 series and 14 from the JA-2 series were randomly selected and individually tested. The nozzles were placed on the test bench and fitted with a plastic tube to direct the sprayed liquid into a 2000 mL collection vessel with an accuracy of 10 mL. Tests were conducted at four pressures: the minimum and maximum recommended by the manufacturer. and two intermediate pressures: 414, 620, 1034, and 1448 kPa. Each measurement lasted 60 seconds. with five repetitions. Statistical analysis of the data consisted of determining measurement accuracy using the Student t test for a 95% confidence interval. Equation 1 was used to determine the flow measurement error. The maximum allowable error for this type of study was 5%. For the calculated error below the established limit. the average was accepted as representative of the sample (Sánchez. 1988).

$$L = \frac{t * DP}{\sqrt{n}} \tag{1}$$

where:
L = absolute error. L;
t = Student's t-score;
SD = standard deviation;
n = number of samples.

From the absolute error determination. the percentage error relative to the mean was calculated. A table was created using Excel to perform the calculations. Another study was conducted to determine the coefficient of discharge (CD). This coefficient utilizes all the factors that characterize the discharge dynamics of a given nozzle (Rodrigues *et al.* 2004). The velocity of the liquid as it passes through the nozzle orifice is critical to the spraying process.

It can be calculated using Equation 2 (Srivastava *et al.* 1993).

Table 1. Nominal flow rate of the evaluated hydraulic vacuum cone nozzles Pressure (kPa). Nominal flow rate (L min-1) JA-1 nozzle JA-2 nozzle 414 0.32 0.64 620 0.38 0.76 1034 0.50 1.00 1448 0.55 1.10, Source: Jacto S.A.

Pressure (kPa)	Nominal flow rate (L min^{-1})	
	Nozzle JA-1	Nozzle JA-2
414	0.32	0.64
620	0.38	0.76
1034	0.50	1.00
1448	0.55	1.10

$$v_i = C_v\left[2\frac{\Delta p}{\rho_1}\right]^n \tag{2}$$

where:
vi = liquid velocity. m s^{-1};
C_v = velocity coefficient;
Δp = total pressure. Pa;
n = coefficient that depends on the flow regime and the type of emitter; for turbulent flow. it is equal to 0.5;
ρ_1 = liquid density. kg m^{-3}.

The flow rate provided by the nozzle is another important factor and can be determined by Equation 3 (Srivastava *et al.* 1993).

$$Q = v * C_A * A \tag{3}$$

where:
Q = nozzle flow rate, m^3 s^{-1};
v = jet velocity, m s^{-1};
C_A = area coefficient;
A = nozzle orifice área, m^2.

The area coefficient accounts for the contraction of the liquid as it passes through the orifice. Combining equations 2 and 3. the nozzle flow can be written according to equation 4 (Srivastava *et al.* 1993).

$$Q = C_v\left[2\frac{\Delta p}{\rho_1}\right]^{\frac{1}{2}} C_A * A \tag{4}$$

The flow coefficient can be calculated using Equation 5. which ultimately allows the flow rate to be determined according to Equation 6.

$$C_D = C_v * C_A \tag{5}$$

$$Q = C_D * A(2gh)^{\frac{1}{2}} = C_D * A\left[2\frac{\Delta p}{\rho_1}\right]^{\frac{1}{2}} \tag{6}$$

The coefficient of discharge depends on the size and design of the orifice and represents the relationship between the actual and theoretical possible flow. Therefore. for a given nozzle. the liquid flow delivered by the nozzle is related to the square root of the pressure. The slope of this line will be C_DA/. from which the coefficient of discharge (C_D) can be determined. The value of the coefficient of discharge (C_D) should be close to 0.611. a value used for orifices with turbulent flow (Srivastava *et al.* 1993).

RESULTS AND DISCUSSION

Flow measurements were made with an error of less than 1% in all cases. falling below the maximum limit of 5% proposed by Sánchez (1988). With these values. the calculated average flow rate can be considered representative of the sample. Nozzle JA-1 had an average flow rate of 0.297 L min^{-1} at a pressure of 414 kPa, reaching 0.574 L min^{-1} at a pressure of 1447 kPa (Figure 1), similar to those proposed by the manufacturer. Nozzle JA-2 had an average flow rate of 0.575 L min^{-1} at the lowest pressure and 1.146 L min^{-1} at the highest. JA-2 had twice the flow rate of JA-1 at the same pressure. a characteristic that will allow different flow rates to be obtained when calibrating the equipment. The comparative analysis between the flow rates obtained and those provided by the manufacturer was performed using the L&O statistical method (Leite & Oliveira. 2002). Another analysis was performed using the Fisher "F" test and the behavior of the residues analyzed using the "T" test. A correlation coefficient analysis was also performed. With these three analyses. it can be considered that the values obtained experimentally are statistically similar to those provided by the manufacturer with a 1% significance level. The experimental results confirm that the flow rates measured in both nozzles (JA-1 and JA-2) do not present statistically significant differences ($p > 0.01$) with respect to the values provided by the manufacturer. which validates the reliability of the technical specifications under controlled conditions. This finding is consistent with previous studies according to ISO 5682-1 (2022) on the calibration of hydraulic nozzles.

Figure 2 shows the flow curves versus the square root of pressure for the experimental data. It can be seen that the performance of each nozzle is represented by the fitting equation used to determine the discharge coefficient.

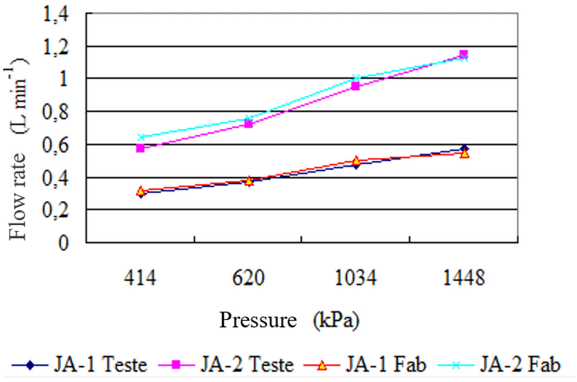

Figure 1. Nozzle Flow rates provided by the manufacturer and obtained in the laboratory. for four working pressures.

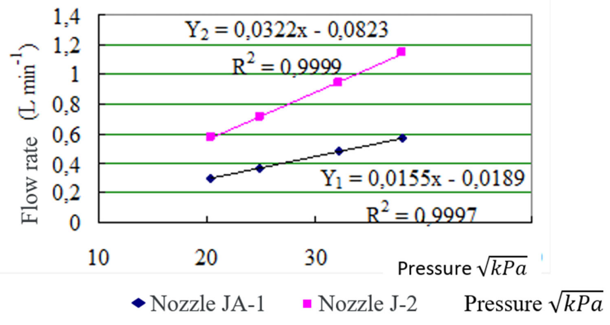

Figure 2. Flow curves as a function of the square root of pressure for the experimental data.

It can be seen that the performance of each nozzle is represented by the fitting equation used to determine the coefficient of discharge. The coefficient of discharge calculated from the values in Figure 2 was 0.232 for nozzle JA-1 and 0.286 for nozzle JA-2. These averages are considerably lower than the 0.611 accepted for turbulent flow orifices. Srivastava et al. (1993) obtained a CD equivalent to 0.274 for nozzles with a diameter of 2.39 mm. The CD values (0.233 for JA-1 and 0.286 for JA-2) are significantly lower than the theoretical value of 0.611 for turbulent flow according to Srivastava et al. (1993). which suggests: energy losses due to orifice geometric design or cavitation effects and practical implications to achieve target flow rates. higher pressures are required. increasing the risk of drift (≥15% of droplets <150 µm at >1000 kPa. according to ASABE S572.1. (2023).

CONCLUSIONS

- The experimental results confirm that the flow rates measured in both nozzles (JA-1 and JA-2) do not present statistically significant differences ($p > 0.01$) with respect to the values provided by the manufacturer. which validates the reliability of the technical specifications under controlled conditions.
- The Cd values (0.233 for JA-1 and 0.286 for JA-2) are significantly lower than the theoretical value of 0.611 for turbulent flow. implying energy losses due to orifice geometric design or cavitation effects and practical implications for achieving flow rates. since higher pressures are required. increasing the risk of drift.
- Specific calibration curves for JA-1/JA-2 nozzles were determined. These curves. which are absent in the technical literature. serve as criteria for nozzle selection and as a basis for optimizing hydropneumatic sprayers by adjusting nozzle pressure.

REFERENCES

ASABE S572.1.: Spray nozzle classification by droplet spectra. American Society of Agricultural and Biological Engineers (ASABE). 2023.

BUTLER. E.M.; TUCK. C.; MILLER. P.: “The effect of some adjuvants on sprays produced by agricultural flat fan nozzles”. Crop protection. 127: 104962. 2020. ISSN: 0261-2194.

CUNHA. J.P.A.R.; ALVARENGA. C.B.; TEIXEIRA. M.M.: “Spray drift reduction with air induction nozzles: A review”. Agronomy. 13(2): 456. 2023.

EUROPEAN UNION DIRECTIVE 2019/782.: Sustainable use of pesticides. Inst. Official Journal of the European Union. 2019.

FAO: Guidelines for pesticide application techniques in agriculture. Inst. Food and Agriculture Organization of the United Nations. Rome. Italy. 2021.

FERGUSON. C.J.; CHECHETTO. R.; ADKINS. S.W.; HEWITT. J.A.; CHAUHAN. S.B.; KRUGER. R.G.; O’DONNELL. C.C.: “Effect of spray droplet size on herbicide efficacy on four winter annual grasses”. Crop Protection. 112: 118-124. 2018. ISSN: 0261-2194.

FOQUINO. L.E.S.; CUNHA. J.P.A.R.; FERREIRA. M.C.: “Optimization of pesticide application rates in soybean: A cost-benefit analysis”. Journal of Agricultural Engineering. 54(1): 78-89. 2023.

GARCERÁ. C.; FONTE. A.; MOLTÓ. E.; CHUECA. P.: “Sustainable use of pesticide applications in citrus: A support tool for volume rate adjustment”. International Journal of Environmental Research and Public Health. 14(7): 715. 2017. ISSN: 1660-4601.

GRELLA. M.; GALLART. M.; MARUCCO. P.; BALSARI. P.; GIL. E.: “Ground deposition and airborne spray drift assessment in vineyard and orchard: The influence of environmental variables and sprayer settings”. Sustainability. 9(5): 728. 2017. ISSN: 2071-1050.

ISO 5682/1: Equipment for crop protection - Spraying equipment - Part 2. Inst. International Organization for Standardization (ISO). Geneva. Geneva. 5 p. 1986.

ISO 5682-1: Métodos de prueba para pulverizadores. Inst. nternational Organization for Standardization (ISO). Geneva. Genova. 2022.

ISO 25358: Crop protection equipment - Droplet size measurement - Terminology and standardised methodologies. Inst. International Organization for Standardization (ISO). Geneva. 2023.

LEITE. H.G.; OLIVEIRA. F.T.: “Statistical procedure to test the identity of analytical methods”. Communications in Soil Science and plant Analysis. New York. 7 e 8: 1-23. 2002.

NUYTTENS. D.; DE SCHAMPHELEIRE. M.; BAETENS. K.; SONCK. B.: “Effect of nozzle type and pressure on spray droplet characteristics”. Biosystems Engineering. 225: 1-12. 2023.

RODRIGUES. G.J.: Critérios rastreáveis na aplicaçao de insetcida no controle do bicho mineiro do cafeeiro. Universidade Federal de Viçosa. Tese (Doutorado em Mecanizaçao Agrícola). Universidade Federal de Viçosa. Viçosa. MG. Brasil. 108 p. 2005.

RODRIGUES. G.J.; TEIXEIRA. M.M.; FERREIRA. L.R.; FERNANDES. H.C.; HERRERA. P.M.: “Avaliação de um conjunto de bicos para uso em uma barra para aplicação de herbicidas em lavouras de café em formação”. Revista Ciencias Técnicas Agropecuarias. 13(2): 17-21. 2004. ISSN: 1010-2760.

SÁNCHEZ. D.P.R.: Estadística modelos y métodos. Ed. Alianza. Editorial AS. Madrid. España. 402 p. 1988.

SRIVASTAVA. A.K.; GOERING. C.E.; ROHRBACH. R.P.; BUCKMASTER. D.R.: Engineering principles of agricultural machines. Inst. American society of agricultural engineers (ASAE) St. Joseph. Mich. USA. 265-324 p. publisher: American society of agricultural engineers St. Joseph. Mich. 1993.