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Effect of Filter Types and Sizes on Flow Characteristics of Standard Flat-fan Nozzles

Bahadır SAYINCI

Atatürk University, Faculty of Agriculture, Department of Agricultural Machinery
PO Box 25240, Erzurum, Turkey
bsayinci@atauni.edu.tr

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Abstract: The relation between flow rate (*Q*) and operational pressure (*P*) of standard flat-fan nozzles can be explained by the power regression model $[Q = k \cdot P^n]$, where *"k"* is the orifice coefficient, and *"n"* is the exponent of spray pressure. According to the model, the flow rate of a nozzle is proportional to the square root of the spray pressure, the exponent *(n)* of which is 0.50. This study examined standard flat-fan nozzles of different nominal sizes with slotted filters, cup filters, and cylindrical strainers (40-mesh, 50-mesh, and 80-mesh). The *"n"* coefficient ranged between 0.481 and 0.487. For nozzles with 50-mesh and 80-mesh ball-check strainers, the *"n"* coefficients were 0.551 and 0.570, respectively. The *"k"* constants of the nozzles with ball-check strainers were smaller than those of the other filters and strainers. The *"k"* constant of nozzles ST11001, ST11002, ST11003, ST11004, and ST11006 could be estimated based on their nominal flow rates (0.38, 0.76, 1.14, 1.51, and 2.27 L/min, at 2.8 bar) with the advanced power regression models. The highest pressure fluctuation on the spray line was observed on the no-filter nozzles. Nozzles with ball-check strainers showed the lowest pressure fluctuation. The strainer types shifted the deviation rate from the nominal flow rate of the nozzle. The lowest deviation rate was observed in the nozzles with no filters, slotted filters, or cup filters. The deviation rate from the nominal flow rate of the nozzles with ball-check strainers was -11.4% for 50-mesh strainers and -12.3% for 80-mesh strainers.

Key words: Flat-fan nozzle, flow rate, nominal size, nozzle strainer, spray pressure fluctuation

INTRODUCTION

Standard flat-fan nozzles are widely used in pesticide applications. Manufacturers typically attach these nozzles, nominal spray angle of which is 110°, to sprayers. The exit orifices of these nozzles are ellipsoidal or rectangular holes, with slots in the middle of the V-shaped channel (Zhou et al., 1996). The nominal flow rate of the nozzle increases linearly as the nominal size increases at a constant spray pressure.

Spray pattern quality and flow rate are used to measure nozzle quality. Spray pattern quality, as defined in the International Standards (ISO Standards, 1996), is the first and most important quality after manufacturing. Flow rate of the nozzle is the second parameter used to test its adherence to quality standards. TSE (Turkish Standards Institution) production standards (TS EN Standard, 2008) indicate the deviation limits of flow rates for nozzles with definite nominal size. The production standards are deemed unsuitable if the deviation limits exceed the values determined in the Standards. To test the flow rate, nozzles are randomly selected from production. Using this method, Huyghebaert et al. (2001) found that 20% of the spray nozzles selected randomly from production failed to meet quality standards.

One of the most frustrating problems encountered during pesticide application is clogged spray nozzles. Clogged nozzles decrease the discharge, which can disrupt or completely stop the flow pattern. Nozzles with correctly positioned strainers and screens prevent nozzle clogging and reduce nozzle wear (Hofman and Solseng, 2004).

The mesh size of nozzle screens indicates the nozzle's straining efficiency. Mesh size is the number of screen openings per 25.4 mm. The strainers of agricultural sprayers generally range between 25-mesh and 200-mesh. Impurities in the spray liquid are forced through screens with smaller openings, because the number of openings increases as the mesh size increases. Additionally, wettable powder solutions can clog screens with small openings. It is proposed that the screen size for strainers used at the back of the nozzle body is lower than half of the orifice diameter. The recommended number of screen openings for spray nozzles is 225 pores per cm^2 (Yagcioglu, 1993; Çilingir and Dursun, 2010).

Most manufacturers report the mesh size of screens for certain spray nozzles. This size is modified in reference to the nominal size of the nozzle. In general, 80-mesh to 100-mesh screens are used for small capacity nozzles with flow rates below 0.57 L/min. A 50-mesh is recommended for nozzles with flow rates between 0.8 and 3.8 L/min. At flow rates above 3.8 L/min, a nozzle strainer is not usually necessary if a good baseline strainer is used (Hofman and Solseng, 2004).

Three types of strainers are commonly used in agricultural nozzles: slotted filters, cup filters, and cylindrical strainers. In nozzles with slotted and cup filters, the liquid goes directly to the nozzle body after filtration. Cylindrical strainers are manufactured with and without ball check. While the cylindrical strainers without ball check are widely used at a sprayer, ball check strainers are used with the aim of preventing dripping after spraying. In general, these types of strainers are used with nozzle holders with no membrane. When operational pressure drops to 1.0 bar, the ball in the strainer body closes the fluid line to prevent dripping.

The structural features of strainers, which are one of the crucial parts of a sprayer, may cause head loss, which is created by friction in the line. Most research conducted on spray nozzles involves the discharge coefficient (Leinhard, 1984; Ballester, 1994; Halder et al., 2004; Iqbal et al., 2005; Hussein et al., 2012; Rashid et al., 2012; Yu et al., 2013; Sayıncı et al., 2013), variable-rate nozzle designs (Womac and Bui, 2002), modelling and design parameters for spray nozzles (Altimira et al., 2007, 2009; Soyama, 2013), estimation of spray angle (Zhou et al., 1996), quality and control trials for reference spray nozzles against indicated standards (Womac, 2000), and flow quality for new types of flat-fan nozzles (Huyghebaert et al., 2001).

It is indicated that strainers cause local loss at facilities with hydraulic systems (e.g., pumping stations), while nozzle rating and loss for agricultural sprayers are unknown. The aim of this study is to compare flow characteristics of standard flat-fan nozzles with seven different types of nozzle filters or strainers. This study investigated several issues: pressure fluctuation for different combinations of strainer type and nominal size of the nozzles, relations between flow rate and pressure, deviations from the nominal flow rates of the nozzles, and the relation between nozzle nominal size and orifice coefficient using the power regression models.

MATERIALS and METHOD

Spray nozzles

Five standard flat-fan nozzles with different nominal sizes (11001, 11002, 11003, 11004, and 11006) were used in the study. Table 1 shows their specifications. Nominal sizes of the nozzles and body colors met American Society of Agricultural and Biological Engineers Standards (ASABE Standards, 2009). The nozzles were imported from abroad and easily obtained from the agricultural sectors in Turkey.

Table 1. Technical properties of standard flat-fan nozzles

Technical properties					
	ST11001	ST11002	ST11003	ST11004	ST11006
Material	POM*	POM	POM	POM	POM
Color	Orange	Yellow	Blue	Red	Grey
Nominal spray angle	110°	110°	110°	110°	110°
Orifice, major length (*L*, mm)	0.99	1.54	1.84	2.10	2.83
Orifice, minor length (*W*, mm)	0.22	0.38	0.52	0.64	0.73
V-slot angle (α°)	19°	23°	30°	32°	28°
Entry orifice diameter (D_O, mm)	1.02	1.55	1.85	2.15	2.85
V-slot height (*h*, mm)	1.22	1.25	1.43	1.71	1.86
Orifice, projected area (*PA*, mm^2)	0.20	0.52	0.82	1.06	1.68

* POM: polyoxymethylene

Figure 1 shows major (*L*) and minor (*W*) lengths, V-slot height (*h*), and entry orifice diameter of the nozzle body (D_o), which was measured with a stereo zoom microscope (Olympus SZ60) with micrometer. To measure the projected area (*PA*) of the orifice, images were taken with the stereo zoom microscope-mounted digital camera (Panasonic Lumix DMC-FZ50). The projected area was determined via image processing using Sigma Scan 5.0 software.

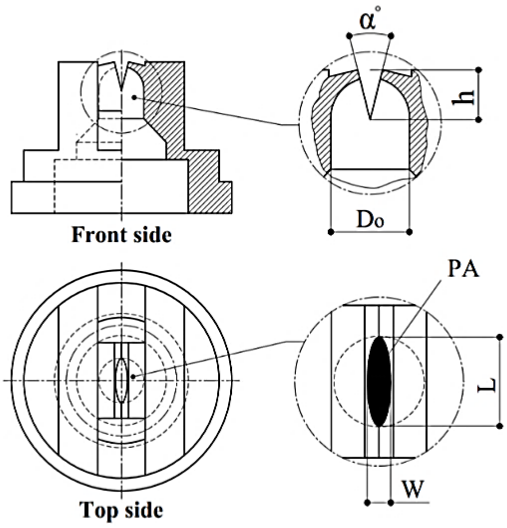

Figure 1. Dimensions of a standard flat-fan nozzle (*α°*: V-slot angle, *h*: V-slot height, D_O: entry orifice diameter, *PA*: projected area, *L*: orifice major length, *W*: orifice minor length)

Nozzle strainers

In the study, seven different types of strainers were used: three cylindrical strainers (40-mesh, 50-mesh, and 80-mesh); two ball check strainers (50-mesh and 80-mesh); a slotted filter; and a screen cup filter. Technical properties of the strainers were given in Table 2. In the Figure 2, technical details of the strainers were displayed.

Sprayer and power unit

In the study, a field sprayer (TP 200 Piton, Taral®, Istanbul, TR) with a 200-liter polyethylene tank was used. The spray boom was 6.0 m. The dry boom had 12 triplet nozzle holders, spaced 50 cm apart. Operational pressure was manually adjusted with a pressure regulator (max. 40 bar, 90 L/min, RG-7 Model) that was adjustable as non-gradual.

Operational pressures were read from a manometer with glycerin, with an indicator range of 0.5 bar max. to 25 bar. The sprayer pump (Tar30 type, Taral®, Istanbul, TR) was driven with an indicator motor (AGM 100L 4a type, Gamak, Istanbul, TR). Rotation transmission of the motor shaft to the pump shaft was provided with a belt-pulley mechanism, and rotation of the motor shaft decreased the rate to 1/2.8. Table 3 shows technical properties of the pump and power unit used in the sprayer.

Table 2. Technical properties of the nozzle strainers

Technical properties	Cylindrical strainers			Ball check strainers		Slotted filter	Cup screen 50 mesh
	40 mesh	50 mesh	80 mesh	50 mesh	80 mesh		
Screen material	Cr-Ni	Cr-Ni	Stainless steel	Cr-Ni	Stainless steel	Brass	Cr-Ni
Type	Screen	Screen	Perforated sheet	Screen	Screen	Slotted	Screen
Screen shape	Square (0.5×0.5)	Square (0.3×0.3)	Hexagon	Square (0.3×0.3)	Hexagon	Slot (0.3 mm) Total: 8	Square (0.3×0.3)
Body material	POM	POM	POM	POM	POM	Brass	POM
Number of openings per cm^2	225	361	238	361	238	-	361
Number of openings per cm	15	19	Hor:14; Ver:17	19	Hor.:14; Ver.:17		19
Diameter of screen wire (mm)	0.18	0.18	-	0.18	-	-	0.18
Total area of an opening on strainer body (mm^2)	0.237	0.120	0.056	0.120	0.056	4.050	0.120
Opening area per cm^2 (mm^2)	53.3	43.3	13.3	43.3	13.3	-	43.3
Strainers body entry opening area (ΣOA, mm^2)	20.0	24.0	12.0	24.0	12.0	32.0	78.5
Strainers body exit opening area (mm^2)	28.3	28.3	14.5	28.3	14.5	50.2	78.5

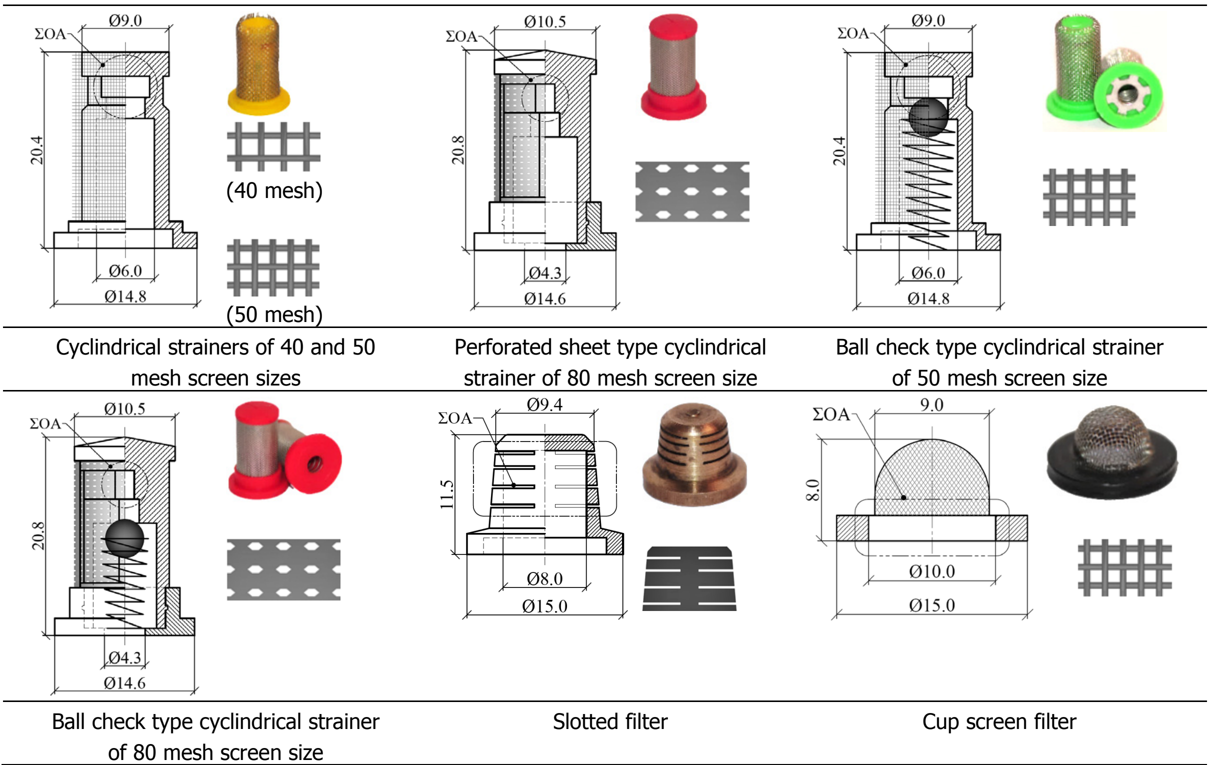

Figure 2. Technical details of the nozzle strainers and screen patterns

Table 3. Technical properties of the pump and power unit used in the sprayer

Sprayer pump	
Flow rate	30 L/min
Revolution	500 min^{-1}
Pressure	0-39.2 bar
Number of membranes	2
Pump yield	67%
Indicator motor	
Definition	AC indicator motor
Nominal power	2.2 kW
Nominal shaft revolution	1405 min^{-1}
Coefficient of power (cos φ)	0.78
Motor yield	79.8%

Measurement of nozzle flow rate

The nozzle flow rates for each of seven different strainer types were measured at five operational pressure levels (1.5, 3.0, 4.0, 6.0 and 8.0 bar). Flow rate measurements were also obtained without using strainers. Six nozzles of the same nominal size were used at each treatment, and flow rate measurements of each nozzle were replicated two or seven times. Flow rates of the nozzles were determined with a flow meter (Nozzle calibrator, 0.08-3.79 L/min, ±%2.5 accuracy, SC-1 Model, SpotOn®, IL). Tap water was used for the measurements, and the sprayer tank was continuously filled with water during spraying. After treatments, all nozzles and strainers were cleaned with compressed air. The maximum deviation limits of the nozzle flow rates ranged between ±10% (ASABE Standards, 2006). Treatments were conducted indoors, where the temperature and relative moisture fluctuated between 10.3 °C and 18.4 °C and between 25% and 53%, respectively. Temperatures of the spraying liquid measured under the exit orifice of the nozzle ranged from 14.5 °C to 15.9 °C.

The operational pressures were the values read from the manometer, which was mounted on the pressure regulator. Spray pressure was measured separately using a digital manometer (Ref D2, %0.1, 0-400 bar, SİKA GmbH & Co. KG), because the liquid pressure decreased between the pump and nozzle holder as a result of head loss (Thornhill and Matthews, 1995). All measurements were recorded for each combination of nozzle, strainer, and operational pressure. Spray pressures were read from the digital manometer after the manometer on the pressure regulator was adjusted to the operational pressure. The difference between the operational pressure and the spray pressure was recorded as pressure fluctuation.

Relation between flow rate and spray pressure

The relation between volumetric flow rate was measured for the combinations, the nominal size, and strainer type of the nozzle. Spray pressure was tested with regression analysis using different curve estimating models. The power model was the best model for estimating flow rate and spray pressure. The determination coefficient (R^2) indicated the relation between both parameters. The power equations are given in the model $[Q = k \cdot P^n]$ (ASABE Standards, 2009). The *"k"* and *"n"* values in the model indicate the orifice coefficient, and exponent of the spray pressure, respectively.

Relation between orifice coefficient and nominal flow rate of nozzle

The relation between mean *"k"* constant and nominal flow rate (Q_{nom}) of the nozzle was determined using regression analysis. According to the regression estimating results, the power model provided the best estimate. The nominal flow rates of the nozzles were independent variables in the statistical analysis. The power equations were stated in the model $[k = m \cdot Q_{nom}^n]$. The estimated parameters (*k* and *m*) show that the relation between both variables was tabulated.

Individual flow rate deviation of the nozzle

The effect of the nozzle strainers on flow rate deviation was checked by comparing their actual flow rate (Q_{act}) with the nominal flow rate (Q_{nom}). The flow rate deviation (φ) was defined as the relative deviation between actual and nominal flow rates, as shown in Equation (1):

$$\varphi = \left(\frac{Q_{act} - Q_{nom}}{Q_{nom}}\right) \times 100 \qquad (1)$$

where

φ : flow rate deviation of the nozzle (%)

Q_{act} : actual flow rate of the nozzle (L/min)

Q_{nom} : nominal flow rate of the nozzle (L/min).

Table 4 shows the nominal flow rates of the nozzles. The nominal flow rates corresponding to the spray pressure of 2.76 bars were calculated with the power regression equations $[Q = k \cdot P^n]$ derived in the study. The flow rate deviation with the positive values indicate that the actual flow rate exceeded the nominal flow rate of the nozzle, while the negative values indicate that the measured flow rate was lower than that of the nominal flow rate of the nozzle.

Table 4. Nominal flow rates of the nozzle

Nominal size	Nominal flow rate (*Q*, gal/min) (2,76 bar=40 PSI)	Nominal flow rate (*Q*, L/min)* (2,76 bar=40 PSI)
ST11001	0.10	0.38
ST11002	0.20	0.76
ST11003	0.30	1.14
ST11004	0.40	1.51
ST11006	0.60	2.27

*: *Q*, L/min: [3.785×nominal flow rate, (gal/min)]

Statistical analysis

The effects on pressure fluctuation, the orifice coefficient *(k)*, the exponent of the spray pressure (*n*), and the flow rate deviation of the nozzles with different nozzle strainer types were tested with variance analysis (ANOVA). Using a completely randomized design, SPSS statistical software (IBM SPSS® Statistics, 2010) was used to analyze variance with a 95% confidence level (P=0.05). Duncan's multiple comparison test was used to determine significant differences.

RESULTS and DISCUSSION

Pressure fluctuation

Table 5 presents the variance analysis results of the factors affecting pressure fluctuation between operational and spray pressure of the nozzle. The effect on pressure fluctuation of nozzle nominal size, strainer type, and operational pressure was statistically very significant (P<0.01). According to the nozzle nominal size, the strainer types and operational pressure substantially influenced pressure fluctuations.

Table 5. Factors affecting pressure fluctuation

Factors and interactions	DF	Mean of squares	Sig. level
Nominal size (NS)	4	55.134	0.000**
Strainer type (ST)	7	0.123	0.000**
Oper. pressure (OP)	4	19.490	0.000**
NS x ST	28	0.024	0.000**
NS x OP	16	2.687	0.000**
ST x OP	28	0.003	0.876 ns
NS x ST x OP	112	0.004	0.928 ns
Error	1000	0.005	
Total	1199		

**: very significant (p<0.01); ns: insignificant

Table 6. Effect of nozzle nominal size and strainer type on pressure fluctuation (mean±SD, bar)

Strainer type	ST11001	ST11002	ST11003	ST11004	ST11006	Means
No-filter	-0.047±0.051	0.120±0.119	0.343±0.216	0.653±0.362	1.200±0.614	0.454±0.554 a*
Cup filter, 50-mesh	-0.040±0.050	0.067±0.115	0.327±0.202	0.620±0.357	1.213±0.607	0.437±0.558 b
Slotted, brass	-0.060±0.050	0.113±0.122	0.293±0.212	0.647±0.369	1.207±0.604	0.440±0.559 ab
Cylindrical, 40-mesh	-0.053±0.051	0.080±0.135	0.320±0.235	0.620±0.357	1.160±0.588	0.425±0.544 b
Cylindrical, 50-mesh	-0.040±0.050	0.080±0.140	0.293±0.212	0.647±0.369	1.193±0.612	0.435±0.559 b
Cylindrical, 80-mesh	-0.040±0.050	0.087±0.133	0.320±0.201	0.613±0.354	1.133±0.583	0.423±0.529 b
Ball check, 50-mesh	-0.040±0.050	0.047±0.111	0.260±0.216	0.567±0.331	1.047±0.588	0.376±0.508 c
Ball check, 80-mesh	-0.047±0.051	0.053±0.133	0.273±0.212	0.553±0.352	1.060±0.554	0.379±0.506 c
Means	-0.046±0.050E	0.081±0.127 D	0.304±0.212C	0.615±0.353B	1.152±0.589A	

* Means followed by the same letter (a-c and A-E) are the same, as determined by the Duncan test at a 5% significance level

Table 6 presents the effect of the pressure fluctuation on the nozzle nominal size and strainer type. The pressure fluctuation means of the ST11001 nozzle, which has the lowest nominal size, showed negative values, because the mean spray pressure of 46 mbar was unexpectedly higher than the operational pressure. This situation may be caused by minor difference in the reading sensibilities of the two manometers. The means with positive marks in the table show that the spray pressure was lower than the operational pressure. Duncan's test revealed that the pressure fluctuations substantially increased as the nominal flow rate of the nozzles increased, and the differences between means were significant. The nozzles with no-filters had the highest pressure fluctuation, while the nozzles with ball check strainers had the lowest pressure fluctuation.

According to hydraulic principals, when liquid is replaced between two points along a pipe, head loss occurs in the pipe. This head loss is caused by pressure fluctuation that results from friction along the pipe walls. Head loss is approximately related to the square of the liquid velocity, so it increases quickly. When liquid velocity decreases, head loss along the pipeline decreases. Conversely, if the pipe section diameter or flow area decrease, the liquid velocity increases and thus head loss increases (Bloch and Budris, 2004). Accordingly, the liquid velocity for nozzles without filter was higher than that of the others, because of the highest pressure fluctuation mean. The higher liquid velocity means a higher flow rate. Remarkably, the nozzles with ball check strainers had the lowest pressure fluctuation mean.

As shown in Figure 3, the pressure fluctuations in the high-capacity nozzles linearly increased with operational pressure. The ST11006 nozzle showed the highest pressure fluctuation.

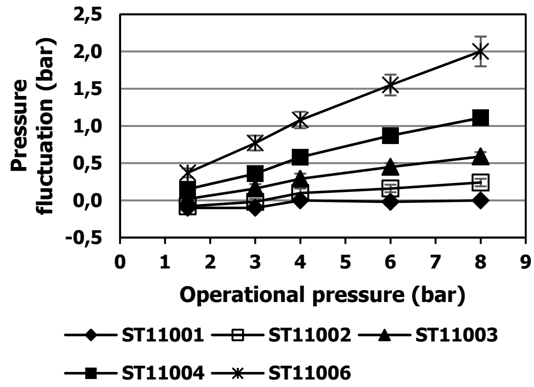

Figure 3. Spray pressure fluctuation according to the operational pressure for nozzles of different nominal sizes

Relation between nozzle flow rate and spray pressure

The power model of $[Q = k \cdot P^n]$ shows the relation between flow rate and spray pressure of a spray nozzle. Table 7 and Table 8 show the mean of the *"k"* constants (orifice coefficient) and *"n"* coefficients (exponent of spray pressure), according to nozzle nominal size and strainer type. The determination coefficients showing the relation between *"k"* and *"n"* are given in Table 9. According to their parameter estimations, R^2 values showing the relation between flow rate and spray pressure are close to 1. The variance analysis showed that the effect of strainer type had a very significant effect on the variation of the orifice coefficient *(k)*. Remarkably, the *"k"* mean of the nozzles without a strainer was statistically the same as for those with the cup filter and slotted strainer. The *"k"* means of the no-filter, cup filter, and slotted strainer ranged from 0.720 to 0.724. The *"k"* means of the cylindrical strainers ranged from 0.705 to 0.711, and the difference between their means was insignificant. The lowest orifice coefficient *(k)* was found for the nozzles with ball check strainers. A distinct feature was observed for the strainer types and nozzles. The *"k"* means of the nozzles with ball check strainers showed the lowest values for nozzles with different nominal sizes.

Table 7. Comparison of orifice coefficient *(k)* according to nozzle strainer types in the power regression model of $[Q = k \cdot P^n]$ (mean±standard deviation, $\bar{X} \mp SD$)

	Nozzle nominal size					
Strainer types	ST11001	ST11002	ST11003	ST11004	ST11006	Means
No-filter	0.234±0.007	0.457±0.006	0.679±0.017	0.929±0.022	1.321±0.034	0.724±0.384 a*
Cup filter, 50-mesh	0.237±0.004	0.444±0.005	0.682±0.016	0.919±0.035	1.335±0.018	0.723±0.389 a
Slotted, brass	0.237±0.008	0.450±0.009	0.666±0.012	0.916±0.033	1.329±0.024	0.720±0.386 ab
Cylindrical, 40-mesh	0.232±0.007	0.447±0.005	0.657±0.012	0.915±0.034	1.297±0.030	0.709±0.378 bc
Cylindrical, 50-mesh	0.239±0.005	0.443±0.004	0.666±0.013	0.896±0.030	1.308±0.022	0.711±0.378 bc
Cylindrical, 80-mesh	0.233±0.007	0.439±0.003	0.674±0.021	0.902±0.030	1.278±0.034	0.705±0.371 c
Ball check, 50-mesh	0.177±0.004	0.368±0.006	0.601±0.022	0.829±0.020	1.145±0.045	0.624±0.347 d
Ball check, 80-mesh	0.186±0.005	0.330±0.004	0.531±0.018	0.805±0.019	1.222±0.017	0.615±0.374 d
Means	0.222±0.024	0.422±0.044	0.644±0.052	0.889±0.051	1.279±0.067	

* Means followed by the same letter (a–d) are the same, as determined by the Duncan test, at a 5% significance level.

Table 8. Comparison of exponent coefficient *(n)* according to nozzle strainers types in the power regression model of $[Q = k \cdot P^n]$ ($\bar{X} \mp SD$)

	Nozzle nominal size					
Strainer types	ST11001	ST11002	ST11003	ST11004	ST11006	Means
No-filter	0.479±0.008	0.476±0.004	0.481±0.005	0.487±0.005	0.483±0.008	0.481±0.007 c*
Cup filter, 50-mesh	0.470±0.008	0.491±0.007	0.476±0.012	0.493±0.014	0.482±0.006	0.482±0.013 c
Slotted, brass	0.466±0.011	0.487±0.008	0.494±0.006	0.487±0.011	0.481±0.008	0.483±0.013 c
Cylindrical, 40-mesh	0.483±0.011	0.487±0.005	0.497±0.010	0.488±0.012	0.482±0.009	0.487±0.011 c
Cylindrical, 50-mesh	0.469±0.006	0.492±0.007	0.489±0.008	0.491±0.008	0.480±0.012	0.484±0.012 c
Cylindrical, 80-mesh	0.485±0.009	0.495±0.004	0.478±0.013	0.494±0.008	0.482±0.009	0.487±0.011 c
Ball check, 50-mesh	0.612±0.016	0.585±0.012	0.527±0.015	0.514±0.010	0.518±0.028	0.551±0.043 b
Ball check, 80-mesh	0.578±0.010	0.641±0.006	0.607±0.017	0.537±0.011	0.487±0.009	0.570±0.056 a
Means	0.505±0.054B	0.519±0.057A	0.506±0.043B	0.499±0.019C	0.487±0.017D	

*: Means followed by the same letter (a–c and A–D) are the same, as determined by the Duncan test, at a 5% significance level.

Table 9. Determination coefficient (R^2) of the power regression model determined from the relation between flow rate and spray pressure

	Nozzle nominal size				
Strainer type	ST11001	ST11002	ST11003	ST11004	ST11006
No-filter	0.995	0.998	0.993	0.994	0.994
Cup filter, 50-mesh	0.995	0.998	0.995	0.992	0.996
Slotted, brass	0.995	0.998	0.995	0.991	0.994
Cylindrical, 40-mesh	0.995	0.998	0.994	0.993	0.995
Cylindrical, 50-mesh	0.995	0.998	0.995	0.993	0.993
Cylindrical, 80-mesh	0.994	0.999	0.994	0.993	0.994
Ball check, 50-mesh	0.993	0.992	0.993	0.994	0.993
Ball check, 80-mesh	0.994	0.991	0.981	0.996	0.997

The *"k"* constant of the spray nozzles, which is referred to as the "orifice coefficient" (ASABE Standards, 2009), is a rate of flow rate and spray pressure $(k = Q/P^n)$. A higher "*k*" constant means that the flow rate of a nozzle increases. The confidence level of the predictions calculated from the power regression model was considerably high because of their R^2 values. The results obtained from the *"k"* constant showed that the cup filter and slotted strainer did not change the flow characteristics of the nozzles and that these strainers did not limit the nominal flow. The flow in the nozzles with ball check strainers had to overcome the resistance of the spring, which helps to minimize drips after spraying. The filter manufacturer indicated that the minimum operating pressure of the ball check strainers changes between 0.3 and 2.8 bar (Agrotop GmbH, 2014). Thus, resistance is an important cause of velocity losses. In pipeline systems, the pressure losses can be calculated using the Darcy-Weisbach equation $[\Delta P = f \cdot (L/D) \cdot (\rho V^2/2)]$ (*ΔP*: pressure loss, mSS; *f*: Darcy friction factor; *L*: length of pipe, m; *D*: diameter of pipe, m; *ρ*: specific weight of liquid, kp/m^3; *V*: velocity of fluid, m/s) (Çengel and Cimbala, 2008). According to the equation, the decreased flow velocity caused by head loss leads to pressure loss. At a constant section of the pipe, the flow rate of the nozzle decreases as the flow velocity decreases.

The strainer types had a statistically very significant effect on variation of the exponent coefficient (*n*) of the nozzle flow rate ($P<0.01$), which is derived in the power regression model. The 80-mesh ball check strainer had the highest mean of the *"n"* coefficient. The *"n"* means of strainers with cylindrical, slotted, and cup filters ranged from 0.482 to 0.487, and they were statistically insignificant with no-filter. Remarkably, the value of the *"n"* coefficient tended to decline as the nominal size of the nozzles increased.

The volumetric flow rate of the spray nozzle is proportional to the square root of spray pressure, the exponent *(n)* of which is 0.50. Spraying Systems Co. (2014) has reported the coefficients as 0.44 for full cone nozzles -wide spray and wide square spray, and 0.46 for full cone nozzles -standard square, oval and large capacity. In the present study, the exponent *"n"* coefficients of the nozzles with no-filter and with cylindrical, slotted, and cup filters were lower than 0.50. Conversely, the *"n"* coefficients of the nozzles with ball check strainers were higher than 0.50. The outputs showed that the ball check strainers altered the liquid flow characteristics in the nozzle body.

The variation of the orifice coefficient *(k)* according to the nominal flow rate of the nozzles

The relation between the orifice coefficient and the nominal flow rate of the nozzles has been stated in reference to the power regression model ($k = m \cdot Q_{nom}^{n}$) with a high R^2. Table 10 shows their parameter estimations.

The nominal size of the nozzle indicates the nominal flow rate at a constant spray pressure (2.8 bars or 40 PSI). It is possible to estimate the *"k"* using the parameter estimations of the "*m*" constant and *"n"* coefficient. Thus, the *"k"* constant can be estimated in reference to the nominal flow rate of 0.1, 0.2, 0.3, 0.4, and 0.6 gal/min (0.38, 0.76, 1.14, 1.51, and 2.27 L/min) of nozzles ST11001, ST11002, ST11003, ST11004 and ST11006, respectively.

Table 10. The parameter estimations of the relation between orifice coefficient and nominal flow rate of nozzles in the ($k = m \cdot Q_{nom}^{n}$) model estimations (*k*: orifice coefficient; *m*: constant; Q_{nom}: nominal flow rate of nozzle, gal/min; *n*: exponent coefficient)

Strainer types	Parameter estimations		R^2
	m	*n*	
No-filter	2.206	0.975	0.998
Cup filter, 50-mesh	2.203	0.975	0.998
Slotted, brass	2.175	0.968	0.998
Cylindrical, 40-mesh	2.151	0.970	0.998
Cylindrical, 50-mesh	2.121	0.956	0.998
Cylindrical, 80-mesh	2.121	0.962	0.997
Ball check, 50-mesh	2.083	1.064	0.995
Ball check, 80-mesh	2.042	1.071	0.989

Deviation rate of the nominal flow rate of the nozzles

The effect of different types of nozzle strainers on flow rates was statistically very significant ($P<0.01$). The nominal size of the nozzle also had a significant effect on the deviation rate of the nominal flow rate, as shown in Table 12. The negative values show that the nozzle flow rate was lower than that of the nominal flow rate. Accordingly, the measured flow rate of the nozzles with ball check strainers was lower than the nozzle nominal flow rate. Nozzles with ball check strainers showed the highest deviation, ranging between -12.3% and -11.4%. The deviation means of the cup filter and slotted strainer were similar to the means with no-filter and ranged between 1.7% and 2.1%. The means of the flow rate deviation were significantly different in reference to the nozzle orifice size. The ST11006 nozzle had the highest flow rate deviation. As shown in Table 13, the highest deviation rate (underlined) calculated with a confidence interval of 99% for the nozzles was determined for nozzles with ball check strainers. Remarkably, the sublimit of the deviation rate for the ST11006 nozzle was close to -10%. The sublimit of the 80-mesh cylindrical strainer was out of ±10%, which is an acceptable value in terms of the availability of the nozzles.

As indicated by the TS EN Standard (2008), the highest deviation limit of a nozzle flow rate should be an interval of ±10%. In reference to the deviation limits, the measured flow rate for flat-fan nozzles with ball check strainers was close to the deviation threshold or it exceeded the sublimit of the deviation.

Table 12. Comparison of the deviation (%) means of nozzle flow rate according to strainer type ($\overline{X} \mp SD$)

	Nozzle nominal size					
Strainer types	ST11001	ST11002	ST11003	ST11004	ST11006	Means
No-filter	0.6±2.3	-2.2±1.0	-2.6±2.3	0.6±2.1	-5.1±2.2	-1.7±2.9 a*
Cup filter, 50-mesh	0.9±1.5	-3.5±0.7	-2.7±1.8	0.1±2.6	-4.1±1.6	-1.9±2.6 a
Slotted, brass	0.6±2.2	-2.5±1.2	-3.2±1.9	-0.8±2.7	-4.6±1.9	-2.1±2.6 ab
Cylindrical, 40-mesh	-0.0±2.1	-3.3±0.9	-4.2±1.9	-0.9±2.5	-6.9±1.8	-3.1±3.1 bc
Cylindrical, 50-mesh	1.6±1.9	-3.5±1.0	-3.6±1.8	-2.6±2.5	-6.2±1.5	-2.9±3.1 bc
Cylindrical, 80-mesh	0.9±2.1	-4.2±0.7	-3.6±2.2	-1.7±2.5	-8.2±2.0	-3.4±3.6 c
Ball check, 50-mesh	-12.8±1	-11.9±0.5	-9.7±2.2	-7.7±1.8	-14.7±1.6	-11.4±2.9 d
Ball check, 80-mesh	-11.6±2	-16.3±0.7	-13.4±2	-8.3±1.8	-11.8±1.1	-12.3±3.1 d
Means	-2.5±6.0 A	-5.9±5.0 B	-5.4±4.2 B	-2.7±3.9 A	-7.7±3.9 C	

* Means followed by the same letter (a–d and A–C) are the same, as determined by the Duncan test, at a 5% significance level.

Table 13. The confidence interval of 99% of flow rate deviation means according to nominal size

	ST11001		ST11002		ST11003		ST11004		ST11006	
Strainer types	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
No-filter	-3.2	4.4	-3.9	-0.5	-6.3	1.2	-2.8	4.1	-8.8	-1.4
Cup filter, 50-mesh	-1.6	3.3	-4.6	-2.3	-5.6	0.3	-4.2	4.4	-6.8	-1.4
Slotted, brass	-3.0	4.2	-4.5	-0.5	-6.3	-0.1	-5.3	3.6	-7.7	-1.6
Cylindrical, 40-mesh	-3.4	3.4	-4.7	-1.8	-7.4	-1.1	-4.9	3.2	-9.9	-3.9
Cylindrical, 50-mesh	-1.6	4.8	-5.1	-1.9	-6.6	-0.7	-6.8	1.5	-8.6	-3.8
Cylindrical, 80-mesh	-2.7	4.4	-5.3	-3.1	-7.3	0.1	-5.8	2.4	-11.4	-5.0
Ball check, 50-mesh	-14.5	-11.1	-12.8	-11.0	-13.4	-6.0	-10.8	-4.7	-17.3	-12.2
Ball check, 80-mesh	-14.9	-8.4	-17.5	-15.2	-16.6	-10.2	-11.2	-5.3	-14.7	-14.6

CONCLUSIONS

The study concluded the following:

- The difference (pressure fluctuation) between operational pressure and spray pressure of the nozzles increased as the orifice size increased.
- The strainer type had a parameter that affected pressure fluctuations.
- Compared to low-capacity nozzles, the pressure fluctuation in the high-capacity nozzles changed linearly with operational pressure.
- The nozzles with ball check strainers had the lowest orifice coefficient *(k)* mean. The orifice coefficient of the nozzles that used both the cup filter and slotted strainer was similar to nozzles without a strainer.
- The orifice coefficient can be estimated using the power regression model in reference to the nominal flow rate of the nozzles.
- The flat-fan nozzles with different nominal sizes used with a slotted strainer, a cup filter, and cylindrical strainers had exponent coefficients *(n)* ranging from 0.481 to 0.487. The *"n"* coefficients of the 50-mesh and 80-mesh ball check strainers were 0.551 and 0.570, respectively.
- The strainer type is a significant parameter affecting the flow characteristics of a nozzle.
- The flow rate of the nozzles with ball check strainers showed deviations ranging from -12.2% to -17.2%.

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