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Hydraulic performance evaluation of sand-filled dripper (SFD)

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ABSTRACT

Sand-filled dripper (SFD) is a new emission device. It is a polyethylene micro tube with diameter of 4, 6 and 10 mm and length of 10, 15 and 20 filled with sand grains of uniform diameter of 0.2, 0.8 and 1 mm. The micro tube is closed from both ends by screen pieces. The ultimate objective of this study is to reveal the reacts of on-line sand filled drippers hydraulic performance arising from the differences in the production process and the different technical features to flow variations, where the SFDs were produced at different flow rates and technical features. Twenty-seven sand-filled drippers were produced, each dripper having different technical specifications. These sand-filled drippers were divided into three types according to diameter of the micro tube from which the dripper was made. Discharge rates from the three different types were collected at five different levels of operating pressure (P). SFDs were tested at 50, 100, 150, 200, and 250 kPa pressure values. To determine the flow regime of every SFD, discharge-pressure relationship, the drippers discharge exponent (x), the coefficient of variation of the discharge (C_V), the emission uniformity (EU), and the dripper flow variation (q_{var}) were evaluated at the different operating pressures. Results of the research have been proved that discharge-pressure relationship of on-line sand-filled drippers is in directed proportionate. As that the flow regime for all SFDs of type 4 are laminar flow and unstable flow regime for all SFDs of types 6 and 10. The results showed that the discharge rate of all types of sand-filled drippers generally increases with increasing the operating pressure. Values of C_V and EU of all considered sand-filled drippers at different operating pressures concluded that the drippers are of good quality. This study introduces a new idea for control technology of trickle irrigation systems.

1. Introduction

Trickle irrigation is based on the fundamental concepts of only watering the crop's root zone and keeping the root zone's water content near optimum levels. Drip, trickle, localized, or pressurized irrigation is an irrigation technique by definition. Irrigation water and chemical solutions are connected to drip irrigation systems in the quantities required, which are calculated precisely and at slow rates using mechanical tools known as pointers placed at specific points along the water supply lines (Al-Amoud, 1998; Lamm et al., 2007). There are a number of issues with trickle irrigation. The clogging of emitters is the most serious issue. Point and line-source emitters, in comparison to bubblers and micro sprinklers, have smaller water discharge passages and are more susceptible to physical, chemical, and biological clogging. Commercially available point-source emitters come in a variety of shapes and sizes. Long path, orifice, and pressure compensating emitters are all types of point-source emitters. The exponent in this equation $q = k_d . P^x$ determines the classification: where q represents emitter discharge (volume/time), P represents operation pressure (force/area), and k_d and x represent emitter constants. When x gets close to one, the emitter is classified as a long-path or laminar flow emitter. A pressure compensating emitter has a positive and nearly zero x, whereas an orifice-type point-source emitter has an x of about 0.5 (Keller and Karmeli, 1975; Al-Amoud, 1998).

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Nomenclature	
C_V	The manufacturer's coefficient of variation for point or line source emitters, [%]
K_d	Constant of proportionality that characterizes each emitter
m_w	Mass of the water discharged from the dripper, [kg]
$q_1, q_2 \dots q_n$	Individual discharge, $[L.h^{-1}]$
q_{ave}	Average of emitter discharge $([q_1 + q_2 \dots q_n]/n)$, $[L.h^{-1}]$
q_{max}	Maximum emitter discharge rate in system, $[L.h^{-1}]$
q_{min}	Minimum emitter discharge rate in system, $[L.h^{-1}]$
q_{var}	Emitter flow variation, [%]
ρ_w	Density of the water (equal to 1 $kg.L^{-1}$), $[kg.L^{-1}]$
D	Diameter of sand-filled dripper, [mm]
d	Diameter of sand granules which fill sand-filled dripper, [mm]
E1, E2, …. and E2	Code of SFD
EU	Emission uniformity, [%]
L	Length of sand-filled dripper, [cm]
n	Number of emitters in a sample
N_e	Number of point source emitters per emission point (number of emitters per plant)
P	Operating pressure head at the emitter, [kPa]
q	Discharge rate of emitter (equal to q_{ave}), $[L.h^{-1}]$
S_d	Estimated standard deviation of the discharge rate of the emitters
SFD	Sand-filled dripper
t	Time of the water discharged from the emitter (15 min), [h]
x	Emitter discharge exponent that is characterized by the flow regime

Clogging and emission non-uniformity have been the major problems in the development of drip irrigation. Pressure regulators and pressure-compensating emitters have long been used to achieve the best emission uniformity. On the other hand, pressure-compensating emitters are more complicated and expensive than non-compensating emitters. Micro tubes as small-bore polyethylene tubes can be pierced along laterals to provide simpler passages and thus less susceptibility to clogging (Keshtgar et al., 2013). The system used micro-tube emitters under the low head, which reduced the likelihood of clogging and provided other benefits (Lamm et al., 2007).

Micro tube is recommended as a low cost and easy to install emitters. According to the researchers, the cost is significantly lower than that of traditional emitter systems (Polak, 1998; Bhatnagar and Srivastava, 2003; Singh et al., 2009; Ella et al., 2009). Micro tube is a simple, low-cost emitter that was widely used throughout the world in the early days of drip irrigation (Almedia et al., 2009). Micro-tubes displayed the best coefficient of manufacturer's variation at 0.06, which is good according to ASABE standards. Accordingly, the micro-tubes had the best average EU at 92.8%, which is excellent for low-cost drip irrigation systems (Thompson, 2009). The hydraulic performance of a drip irrigation system with in-line emitters 1.3 $L.h^{-1}$ and 2.4 $L.h^{-1}$ for pressures of 68.6, 88.2, 117.6, and 147 kPa was evaluated. The results showed that as the operating pressure increases, the emission uniformity, uniformity coefficient, and irrigation efficiency increase, while the coefficient of variation and emitter flow variation decrease for all emission devices (Deshmukh et al., 2014). The effect of drip irrigation system as hydraulic performance on emitter discharge, coefficient of variation, and emission uniformity was investigated. The discharge flow rate of the emitter increased as the pressure increased, and the coefficient of variation increased as the pressure decreased, indicating that the pressure directly affected the discharge rate of the emitter (Mistry et al., 2017).

Even today, no research has been done on the evaluation of hydraulic performance of sand-filled dripper (SFD) to find the effects of various dripper design (non-compensating versus compensating) on the uniformity of irrigation water application. So, the main objective of this work was to find more specifics on hydraulic characteristics and head-discharge relationship of sand-filled dripper by collecting discharge rate at five different levels of operating pressure of 50, 100, 150, 200 and 250 kPa to estimate the hydraulic performance of sand-filled dripper, calculate the manufacturer's coefficient of variation (C_V), K_d and x, so as to establish the flow rate sensitivity of SFD to pressure and comparing the results to the on-line emitters which can be find in the market.

2. Materials and methods

2.1. Experiments Location

Laboratory experiments were conducted in the laboratory of irrigation and Hydraulics, Water and Irrigation systems Engineering Department, Faculty of Agricultural Engineering Al-Azhar University, Cairo, Egypt (30°03'15.9"N latitude 31°19'14.9"E longitude) to determine the hydraulic performances for the different types of sand-filled dripper (SFD) under different levels of working pressure.

2.2. Sand-filled dripper (SFD)

El-mesery (2011) designed sand-filled dripper as in Fig. 1. it is consisting of a polyethylene micro tube that filled with homogeneous granular sand, screen pieces at both ends of the micro tube and a barbed end at only one end of the micro tube. To determine the relationship between discharge rate of SFD and operating pressure which the design of drip irrigation systems depends on it. Table 1 summarizes the design specifications for the twenty-seven of sand-filled dripper types which used in the experimental.

2.3. Layout of drip irrigation experimental and set-up

Twenty-seven different types of on-line sand-filled dripper have been laboratory tested to choose the best and use them in the drip irrigation network to irrigate the different crops in the field. The Layout of drip irrigation experimental set-up consisted as in Fig.2 from three irrigation subunits and each sub-unit included three drip lines of 3.5 m length spaced at 0.50 m. Twenty-one sand-filled drippers (as replicates) are installed in each sub-unit (seven drippers in each drip line at distance of 0.50 m. Each sub-unit was used to test one type of SFD. Measuring cylinder, stopwatch and caught cans used to calculate the emitter discharge.

2.4. Data Collection and calculation of SFD discharge

To determine the sand-filled dripper discharge (q), the drip irrigation network was operated under five different levels of operating pressures 50, 100, 150, 200 and 250 kPa for each type of SFD. the gravimetric method was used to measure the discharge volume of SFD where the collected water mass was measured for 15 min. Every sampling emitter has an assigned 3000 mL plastic beaker which its mass was registered before the experiments. After every experiment, the combined mass of the beaker and water collected by each beaker were weighed using a digital scale. The mass of water discharged is calculated by subtracting the mass of the beaker from the combined mass of the cup and water. Assuming the water density is one $kg.L^{-1}$, the discharge rate of SFD can be calculated the following equation (Martinez et al., 2022):

$$q = \frac{m_w}{\rho_w \times t} \quad ... [1]$$

where: q: is the discharge rate of SFD in ($L.h^{-1}$), m_w: is mass of the water discharged from the dripper in (kg), ρ_w: is the density of water in ($kg.L^{-1}$) equal to 1 $kg.L^{-1}$, and t: is time of the water discharged from the dripper in (h) (equal to 15 min).

2.5. Emitter Evaluation

They are some very important parameters to evaluate the performance of emitters. these parameters are emitter discharge (q), the emitters discharge exponent (x), the coefficient of variation of the discharge (C_V), emission uniformity (EU), and emitter flow variation (q_{var}).

2.5.1. Pressure – discharge relationship

The Pressure discharge for emitters was expressed by the following formula (Karmeli, 1977, Keller and Bliesner, 1990).

$$q = k_d . P^x \quad ... [2]$$

where, q: is the discharge rate of dripper in ($L.h^{-1}$), k_d: is discharge coefficient, P: is the emitter working pressure in (kPa) and x: is the emitter flow exponent.

2.5.2. Manufacturer's coefficient of variation (C_V)

Coefficient of manufacturing variation is defined as the ratio of the standard deviation of flow to the mean flow for a sample number of emitters. Coefficient of Variation (C_V) is a statistical parameter expressed by the following equations (Madramootto, 1988; ASAE, 1990; Savva and Frenken, 2002).

$$C_V = \frac{S_d}{q_{ave}} \quad ... [3]$$

$$S_d = \sqrt{\frac{[{q_1}^2 + {q_2}^2 ... + {q_n}^2 - n{q_{ave}}^2]}{[n-1]}} \quad ... [4]$$

where, C_V: is the manufacturing coefficient of variation, q_{ave}: is the average emission rate of sample, S_d: is the estimated standard deviation of the discharge rate of the emitters, $q_1, q_2 ... q_n$: is the individual discharge in ($L.h^{-1}$), n: is number of the emitters in a sample, and q_{ave}: is average the emitter discharge ($[q_1 + q_2 ... q_n]/n$) in ($L.h^{-1}$).

Numerous guidelines have been suggested to classify C_V values, but those given in the ISO standards (International standard, 1991) are used in this study (Table 2).

2.5.3. Emission uniformity (EU)

The design emission uniformity is defined for point and line source emitters by the following equation developed by Keller and Karmeli (1975):

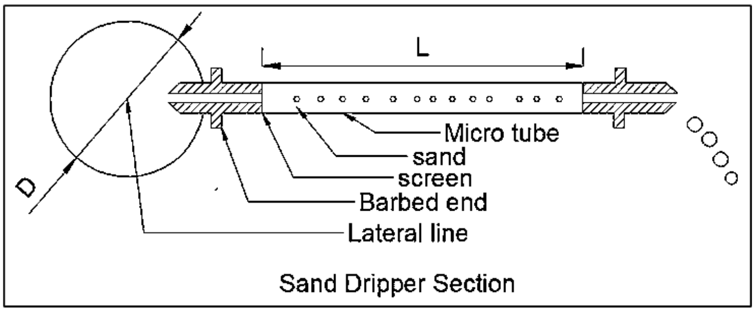


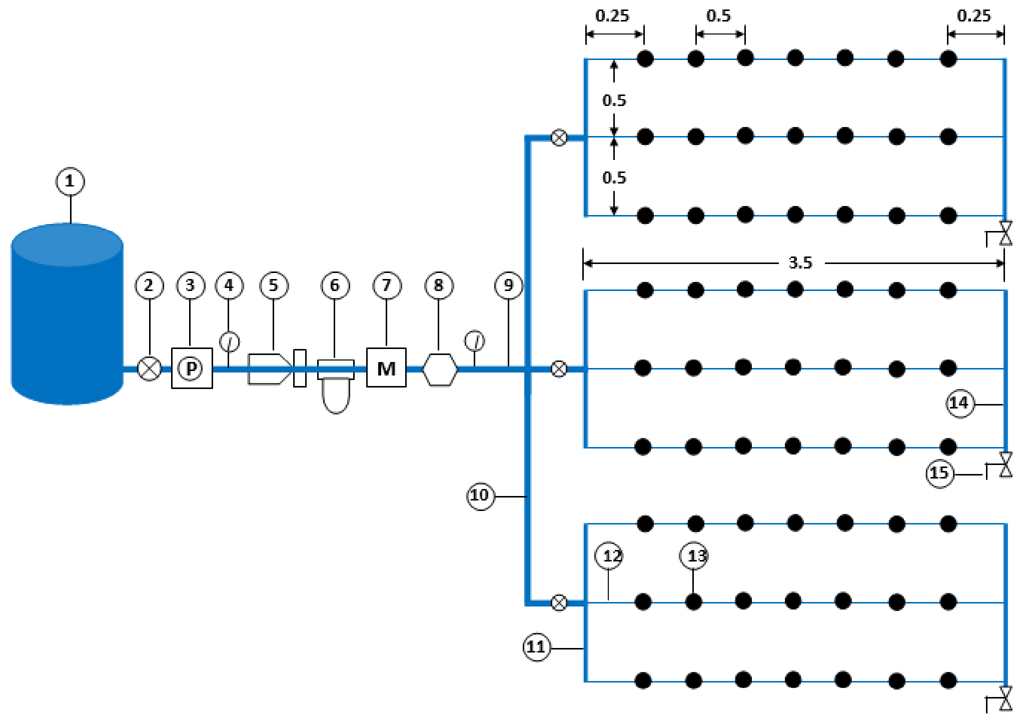
Fig. 1. Typical installation of sand-filled dripper (El-mesery, 2011).

Table 1
Specifications of sand-filled dripper (SFD).

SFD type	SFD code	Specification		
		SFD Diameter "D" (mm)	SFD length "L" (cm)	Diameter of sand granules "d" (mm) which fill SFD.
Type 4	E1	4	10	1
	E2	4	15	1
	E3	4	20	1
	E4	4	10	0.8
	E5	4	15	0.8
	E6	4	20	0.8
	E7	4	10	0.2
	E8	4	15	0.2
	E9	4	20	0.2
Type 6	E10	6	10	1
	E11	6	15	1
	E12	6	20	1
	E13	6	10	0.8
	E14	6	15	0.8
	E15	6	20	0.8
	E16	6	10	0.2
	E17	6	15	0.2
	E18	6	20	0.2
Type 10	E19	10	10	1
	E20	10	15	1
	E21	10	20	1
	E22	10	10	0.8
	E23	10	15	0.8
	E24	10	20	0.8
	E25	10	10	0.2
	E26	10	15	0.2
	E27	10	20	0.2

Table 2
Classifications of Coefficient of Variation Values According to ISO Standards, (1991)

Category	C_V values	Details	Classification
A	0 to±5%	Higher emission of uniformity rate and smaller deviations from the specified nominal emission rate.	Good
B	±5 to±10%	Medium emission of uniformity rate and medium deviations from the specified nominal emission rate.	Medium
C	>10%	Lower emission of uniformity rate and greater deviations from the specified nominal emission rate.	Poor



① Water source (Tank). ② Manual valve. ③ Pumping station. ④ Pressure gauge.
⑤ Check valve. ⑥ Filtration unit. ⑦ Water meter. ⑧ Pressure regulator.
⑨ Main line. ⑩ Sub main line. ⑪ Distribution line. ⑫ Dripperline (Lateral line).
⑬ Drippers. ⑭ Flushing manifold. ⑮ Flushing valve.

Fig. 2. The experimental layout of the drip system (Dimensions in m).

$$EU = 100\left(1 - \frac{1.27}{\sqrt{N_e}}C_V\right)\frac{q_{min}}{q_{ave}} \quad ... [5]$$

where: EU: is the design emission uniformity in percent (%), N_e: is number of point source emitters per emission point (number of emitters per plant), C_V: is the manufacturer's coefficient of variation for point or line source emitters, q_{min}: is the minimum emitter discharge rate in system in $(L.h^{-1})$, and q_{ave}: is the average or design emitter discharge rate in $(L.h^{-1})$.

For point-source emitters, EU values above 90% are considered excellent, between 80% and 90% as good, between 70% and 80% as fair, and between 60% and 70% as poor whereas EU values below 60% would be unacceptable (ASAE, 1999).

2.5.4. *Emitter flow variation (q_{var})*

Flow variation is also a design parameter to evaluate a trickle lateral design. General criteria for q_{var} values are 10% or less, desirable and 10 to 20%, acceptable and greater than 20%, not acceptable by Wu and Gitlin (1983). The defining equation for flow variation as below.

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}} \times 100 \quad ... [6]$$

where: q_{var}: is the flow variation in (%), q_{max}: is the maximum emitter discharge rate in system in $(L.h^{-1})$. q_{min}: is the minimum emitter discharge rate in system in $(L.h^{-1})$.

3. Results and discussions

3.1. *Calibration and evaluation performance of SFDs*

The experiments were conducted to investigate the performance of different SFDs at different working pressures.

3.1.1. *Discharge-pressure relationship of different types of SFD*

Fig.3 illustrate the mean SFD discharge rate for type 4 of SFD (E1, E2, …. and E9) at operating pressure of 50, 100, 150, 200 and 250 kPa. The results in Fig. 3 showed that all used emitters of type 4 discharge rates were increased as the pressure increases from 50 kPa to 100, 150, 200 and 250 kPa. While the discharge rates of SFDs type 4 decreases with increasing in the length of the dripper from 10 to 15 and 20 cm.

Similarly, for remaining SFDs of type 6 (E10, E11, … and E18) and type 10 (E19, E20, … and E27); also, the discharge rate increased with increase in pressure from 50 to 100, 150, 200 and 250 kPa. While the discharge decreased with increase in the length of the SFD from 10 to 15 and 20 cm.

The observed data of discharge rates for type 6 and type 10 of SFDs at various operating pressure and different lengths of SFDs.; also, the relationship between discharge rate and operating pressure are expressed by equation [2] as in Figs. 4 and 5. It is evident from the Figs. 3, 4 and 5 that the discharge and pressure are directly proportionate. The emitter discharge exponent x is a very important factor for hydraulic performance of any dripper. The hydraulic characteristics of all tested SFDs were calculated using regression analysis. The results shown in that the discharge rate of different types of sand-filled drippers increases with increasing operating pressure. The power relationships between pressure and discharge have been developed for each emitter as shown in Figs. 3, 4 and 5. The power form of the mathematical relationships for the discharge-pressure relationships were presented in Tables 3, 4 and 5. The value of R^2 for each SFD discharge was over 0.94 and it can be said that the model fits well.

From Table 3 it can be seen that, in case of the SFDs discharge rates of type 4, the pressure exponent x was greater than or equal to one. This result indicates that the nature of flow regime from the SFD was a flow of microtubes, so that the flow regime for all SFDs of type 4 are laminar flow. While for the SFDs of type 6 the exponent x of pressure Table 4 was ranger from 0.655 to 1.041 so that the flow regime for all SFDs of type 6 are unstable flow regime. Whereas for the SFDs of type 10 the exponent x of pressure Table 5 was ranger from 0.72 to 0.98 so that the flow regime for all SFDs of type 10 are unstable flow regime.

The previous classification of flow regime for all SFD types was according to Keller and Karmeli (1974); Savva and Frenken (2002); Hoffman et al. (2007); Waller and Yitayew (2016) recommended classification of flow regime according to the value of emitter discharge exponent.

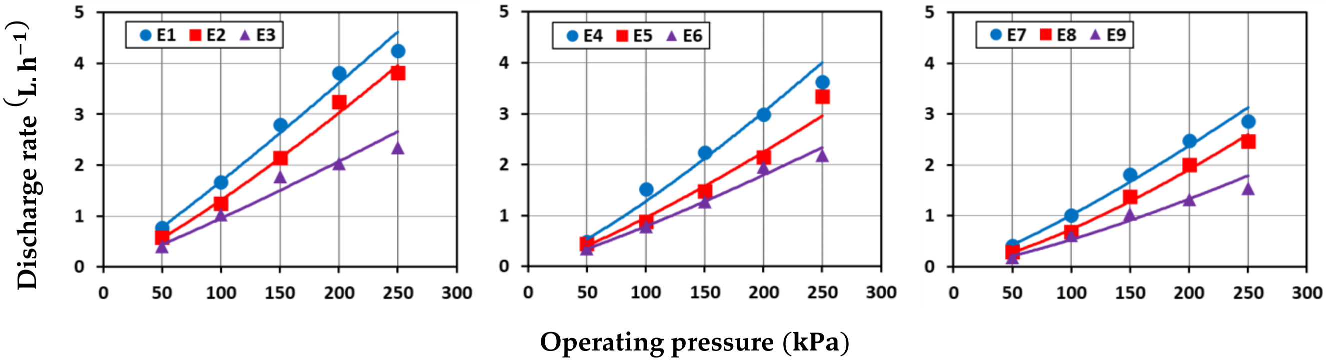


Fig. 3. Effect of working pressure "P" (kPa) on emitter discharge rate "q" ($L.h^{-1}$) for type 4 of SFD.

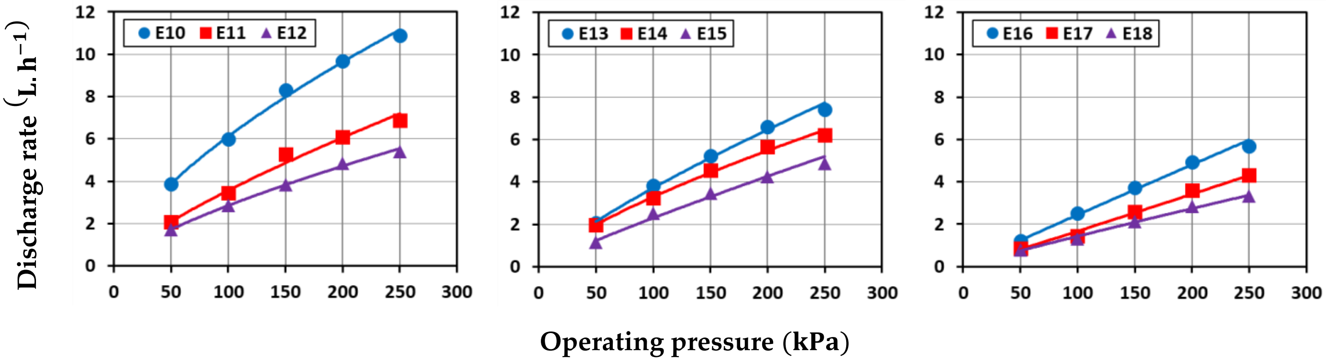


Fig. 4. Effect of working pressure "P" (kPa) on emitter discharge rate "q" ($L.h^{-1}$) for type 6 of SFD.

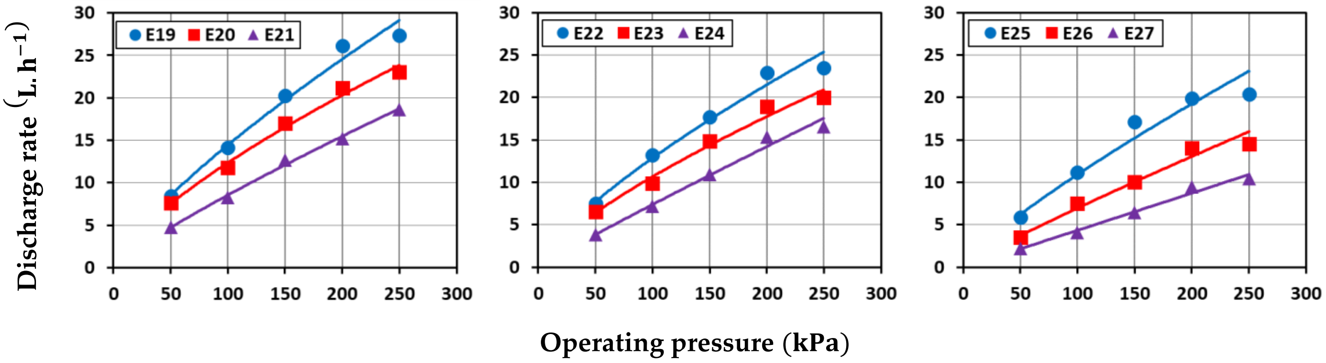


Fig. 5. Effect of working pressure "P" (kPa) on emitter discharge rate "q" ($L.h^{-1}$) for type 10 of SFD.

Table 3
Developed models for the pressure discharge relationship for type 4 of SFD.

SFD code	k_d	x	Developed Model	Goodness of fit (R^2)	Classification
E1	0.010	1.108	$q = 0.010\ P^{1.108}$	0.978	laminar flow
E2	0.005	1.207	$q = 0.005\ P^{1.207}$	0.990	
E3	0.005	1.123	$q = 0.005\ P^{1.123}$	0.945	
E4	0.004	1.246	$q = 0.004\ P^{1.246}$	0.980	
E5	0.006	1.087	$q = 0.006\ P^{1.087}$	0.977	
E6	0.003	1.195	$q = 0.003\ P^{1.195}$	0.979	
E7	0.004	1.232	$q = 0.004\ P^{1.232}$	0.979	
E8	0.001	1.393	$q = 0.001\ P^{1.393}$	0.988	
E9	0.001	1.346	$q = 0.001\ P^{1.346}$	0.954	

Table 4
Developed models for the pressure discharge relationship for type 6 of SFD.

SFD code	k_d	x	Developed Model	Goodness of fit (R^2)	Classification
E10	0.300	0.655	$q = 0.300\ P^{0.655}$	0.994	unstable flow regime
E11	0.106	0.764	$q = 0.106\ P^{0.764}$	0.984	
E12	0.138	0.665	$q = 0.138\ P^{0.665}$	0.995	
E13	0.930	0.801	$q = 0.930\ P^{0.801}$	0.994	
E14	0.113	0.732	$q = 0.113\ P^{0.732}$	0.993	
E15	0.378	0.892	$q = 0.378\ P^{0.892}$	0.983	
E16	0.026	0.987	$q = 0.026\ P^{0.987}$	0.993	
E17	0.014	1.041	$q = 0.014\ P^{1.041}$	0.992	
E18	0.018	0.949	$q = 0.018\ P^{0.949}$	0.994	

Table 5
Developed models for the pressure discharge relationship for type 10 of SFD.

SFD code	k_d	x	Developed Model	Goodness of fit (R^2)	Classification
E19	0.426	0.765	$q = 0.426\ P^{0.765}$	0.977	unstable flow regime
E20	0.455	0.717	$q = 0.455\ P^{0.717}$	0.989	
E21	0.162	0.860	$q = 0.162\ P^{0.860}$	0.995	
E22	0.422	0.742	$q = 0.422\ P^{0.742}$	0.970	
E23	0.356	0.738	$q = 0.356\ P^{0.738}$	0.976	
E24	0.090	0.955	$q = 0.090\ P^{0.955}$	0.980	
E25	0.252	0.818	$q = 0.252\ P^{0.818}$	0.935	
E26	0.103	0.915	$q = 0.103\ P^{0.915}$	0.963	
E27	0.048	0.977	$q = 0.048\ P^{0.977}$	0.960	

3.1.2. Coefficient of variation for different types of SFD

To decision if the system was good, medium and poor, it was needful to determine the coefficient of variation (C_V) of discharge for all types of SFD. The C_V of SFDs in the sample falling within a given deviation from the mean rate of discharge was calculated using equations [3] and [4].

For SFDs of type 4, the results in Fig. 6 indicated that the coefficient of discharge variation values for all SFDs of type 4 were ranged from 10.09% to 16.37% at operating pressure of 50 kPa, from 9.76% to 5.04% at operating pressures ranging from 100 to150 kPa and from 4.99% to 2.26% at operating pressures ranging from 200 to 250 kPa. So, the SFDs of type 4 performance was classified based on the coefficient of variation as good at operating pressures of 200 and 250 kPa, medium at operating pressures of 100 and 150 kPa and poor at operating pressure of 50 kPa according to the recommended classification of ISO standards (1991).

For SFDs of type 6, the results in Fig. 7 indicated that the coefficient of discharge variation values for all SFDs of type 6 were ranged from 9.98% to 5.28% at operating pressures ranging from 50 to 100 kPa and from 4.67% to 1.15% at operating pressures ranging from 150 to 250 kPa. So, the SFDs of type 6 performance was classified based on the coefficient of variation as good at 150 and 250 kPa operating pressures and as medium at 50 and 100 kPa operating pressures according to the recommended classification of ISO standards (1991).

Similarly, for SFDs of type 10, the results in Fig. 8 indicated that the coefficient of discharge variation values for all SFDs of type 10 were ranged from 9.56% to 5.15% at operating pressures ranging from 50 to 100 kPa and from 4.93% to 1.28% at operating pressures raging from150 to 250 kPa. So, the SFDs of type 10 performance was classified based on coefficient of variation as good at 150 and 250 kPa operating pressures and as medium at 50 and 100 kPa operating pressures according to the recommended classification of ISO (1991).

Generally, the coefficient of variation decreased with increasing the working pressure for all types of SFD. Fluctuations in values of the coefficient of variation with pressure possibly used to describe the sensitivity of dripper discharge to pressure. The results in agreement with Pitchford, 1980; Boswell, 1985, they mentioned that the typical values of the coefficient of variation must be ranged from 2% to 15 % to fulfill sensible uniformity of water application although higher values are also possible. Table 6 shows a classification summary of the three types of sand-filled drippers at operating pressures of 50, 100, 150, 200 and 250 kPabased on the coefficient of variation according to the recommended classification of ISO standards (1991).

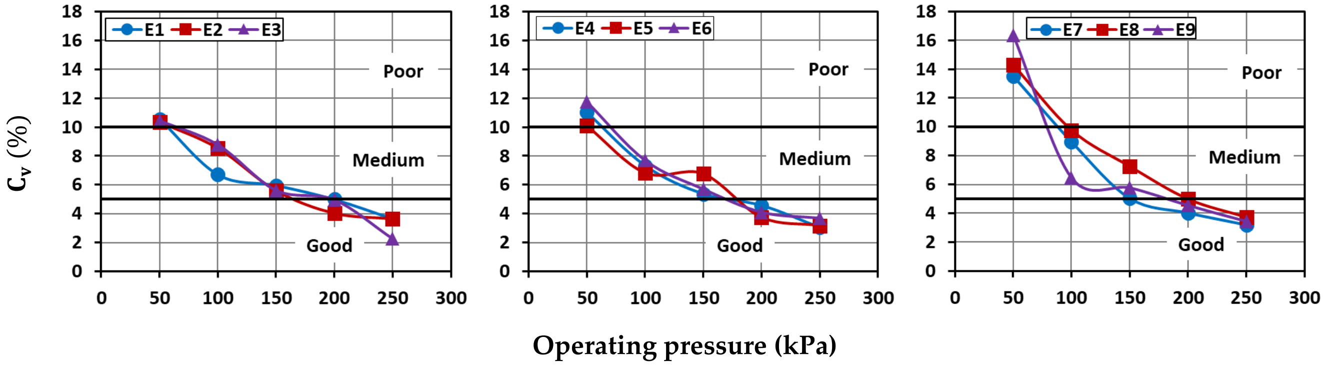


Fig. 6. The experimental data and the relationships between the coefficient of variation "C_v" (%) and operating pressure "P" (kPa) for type 4 of SFD.

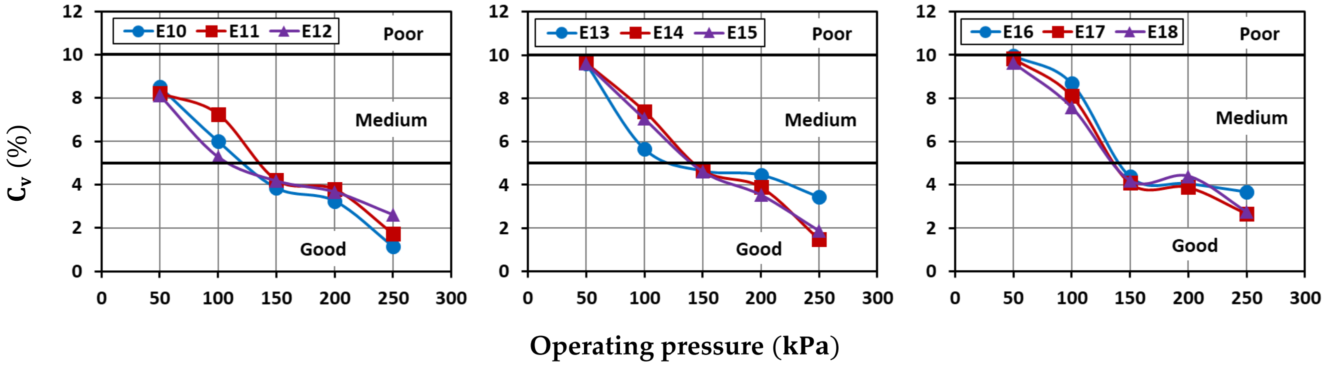


Fig. 7. The experimental data and the relationships between the coefficient of variation "C_v" (%) and operating pressure "P" (kPa) for type 6 of SFD.

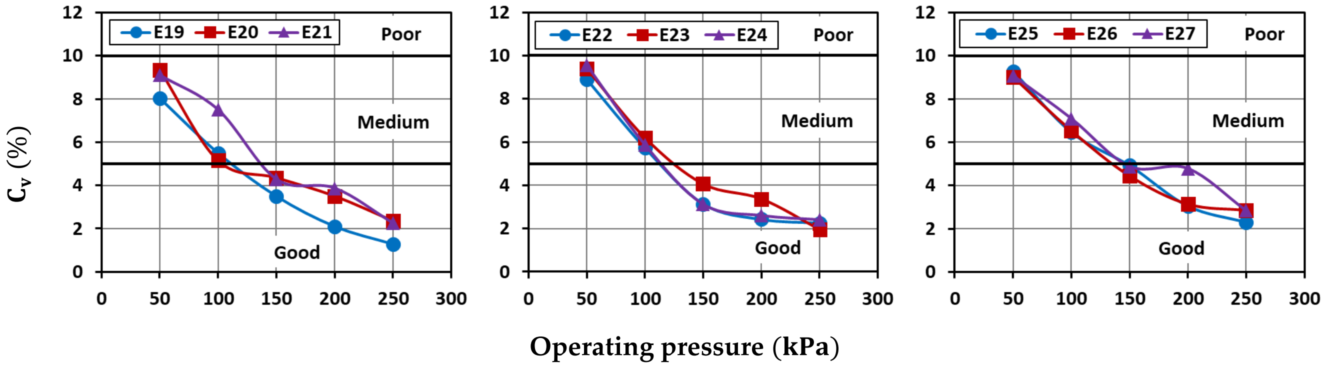


Fig. 8. The experimental data and the relationships between the coefficient of variation "C_v" (%) and operating pressure "P" (kPa) for type 10 of SFD.

Table 6

A classification summary of the three types of SFD at different operating pressures "P" (kPa) based on the coefficient of variation according to the recommended classification of ISO standards (1991).

Type of SFD (SFD code)	Operating pressure "P" (kPa)				
	50	100	150	200	250
	Classification based on C_v				
Type 4 (E1, E2, … and E9)	Poor	Medium	Medium	Good	Good
Type 6 (E10, E11, … and E18)	Medium	Medium	Good	Good	Good
Type 10 (E19, E20, … and E27)	Medium	Medium	Good	Good	Good

3.1.3. Emission Uniformity "EU" (%) of SFDs

Emission uniformity of SFDs was calculated using equation [5] for all types. The relationship between operating pressure and the emission uniformity as shown in Figs 9, 10 and 11. In the case of SFDs of type 4, the results in Fig. 9 indicated that the emission uniformity values were ranging from 80.13% to 89.12% at operating pressures ranging from 50 to 100 kPa and ranging from 87.82% to 95.82% at operating pressures ranging from 150 to 250 kPa. So, the SFDs of type 4 performance was classified based on the emission uniformity as good at 50 and 100 kPa operating pressures and as excellent at 150, 200 and 250 kPa operating pressures according to the recommended classification of ASAE (1999).

Similarly, in the case of SFDs of type 6, the results in Fig. 10 indicated that the emission uniformity values were ranging from 81.41% to 90.75% at operating pressures ranging from 50 to 100 kPa and ranging from 91.60% to 97.89% at operating pressures ranging from 150 to 250 kPa. So, the SFDs of type 6 performance was classified based on the emission uniformity as good at 50 and 100 kPa operating pressures and as excellent at 150, 200 and 250 kPa operating pressures according to the recommended classification of ASAE (1999).

For SFDs of type 10, the results in Fig. 11 indicated that the emission uniformity values were ranging from 82.81% to 87.63% at 50 kPa operating pressure and from 90.03% to 97.73% at operating pressures ranging from 100 to 250 kPa. So, the SFDs of type 10 performance was classified based on the emission uniformity as good only at 50 kPa operating pressure and as excellent at 100, 150, 200 and 250 kPa operating pressures according to the recommended classification of ASAE (1999).

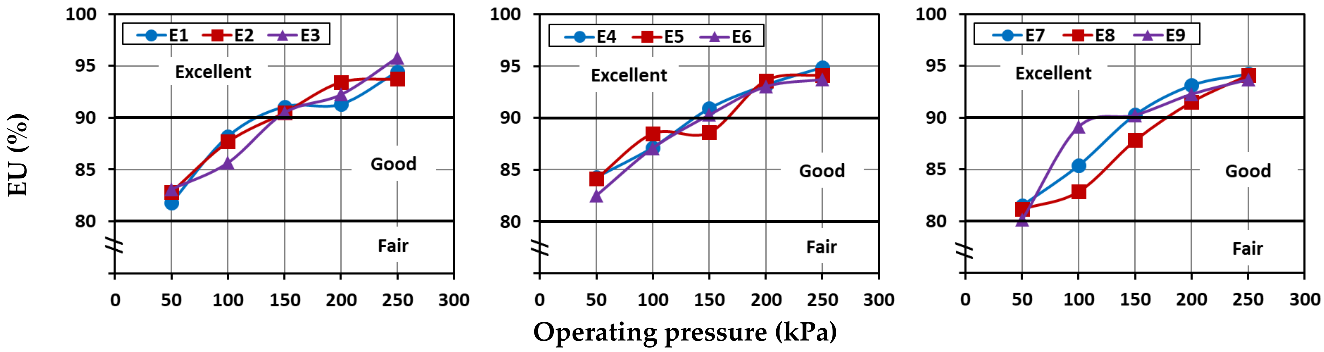


Fig. 9. The experimental data and the relationships between the emission uniformity ''EU'' (%) and working pressure "P" (kPa) for type 4 of SFD.

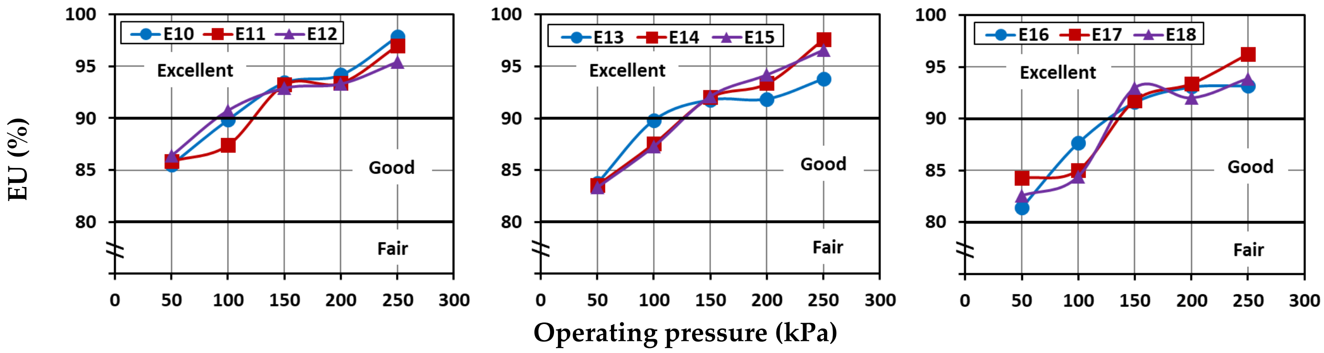


Fig. 10. The experimental data and the relationships between the emission uniformity "EU" (%) and working pressure "P" (kPa) for type 6 of SFD.

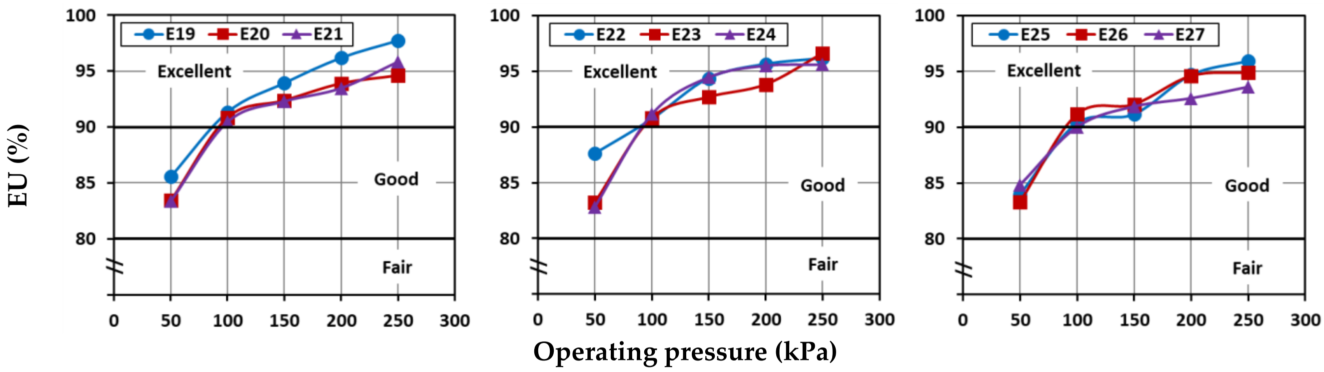


Fig. 11. The experimental data and the relationships between the emission uniformity "EU" (%) and working pressure "P" (kPa) for type 10 of SFD.

Table 7 shows a classification summary of the three types of sand-filled drippers at operating pressures of 50, 100, 150, 200 and 250 kPa based on the emission uniformity according to the recommended classification of ASAE (1999). By comparing the results of the coefficient of variation with the results of the emission uniformity, it was found that there is an inverse relationship between the coefficient of variation and the emission uniformity, where the emission uniformity decreases with an increase in the coefficient of variation. These results in conformity with Solomon, (1979); Hoffman et al. (2007); Kumar and Singh (2007); Pragna et al. (2017).

Table 7
A classification summary of the three types of sand-filled drippers at different operating pressures "P" (kPa) based on the emission uniformity according to the recommended classification of ASAE (1999).

Type of SFD (SFD code)	Operating pressure "P" (kPa)				
	50	100	150	200	250
	Classification based on EU				
Type 4 (E1, E2, … and E9)	Good	Good	Excellent	Excellent	Excellent
Type 6 (E10, E11, … and E18)	Good	Good	Excellent	Excellent	Excellent
Type 10 (E19, E20, … and E27)	Good	Excellent	Excellent	Excellent	Excellent

3.1.4. Flow variation "q_{var}" (%) of SFDs

Calculation of the flow variations of SFD using equation [6] indicate the relationship between the minimum and maximum flow rate variation in percent of the maximum flow value. Values of flow variations for all types of SFD. The relationship between flow variations of SFD and operating pressure as shown in Figs 12, 13 and 14. In the case of SFDs of type 4, the results in Fig. 12 indicated that the flow variation values were ranging from 19.74% to 10.17% at operating pressure ranging from 50 to 150 kPa and from 9.52% to 4.20% at operating pressures ranging from 200 to 250 kPa. So, the SFDs of type 4 performance was classified based on the flow variation as acceptable at 50, 100 and 150 kPa operating pressures and as desirable at 200 and 250 kPa operating pressures as Wu and Gitlin (1983) states.

In the case of SFDs of type 6, the results in Fig. 13 indicated that the flow variation values were ranging from 19.77% to 10.00% at operating pressure ranging from 50 to 100 kPa and ranging from 9.95% to 2.18% at operating pressures ranging from 150 to 250 kPa. So, the SFDs of type 6 performance was classified based on the flow variation as acceptable at 50 and 100 kPa operating pressures and as desirable at 150, 200 and 250 kPa operating pressures as Wu and Gitlin (1983) states.

In the case of SFDs of type 10, the results in Fig. 14 indicated that the flow variation values were ranging from 11.39% to 19.88% at operating pressure 50 kPa and from 9.94% to 2.53% at operating pressures ranging from 100 to 250 kPa. So, the SFDs of type 10 performance was classified based on the flow variation as acceptable at 50 kPa operating pressure and as desirable at 100, 150, 200 and 250 kPa operating pressures as Wu and Gitlin (1983) states. Table (8) shows a classification summary of the three types of sand-filled drippers at operating pressures of 50, 100, 150, 200 and 250 kPa based on flow variation according to the recommended classification of Wu and Gitlin (1983).

4. Conclusions

In this research, a new emission device was designed from simple local materials, and as well as hydraulically evaluated. The results of the research revealed the following: (1) The flow regime of sand-filled drippers of type 4 (SFD diameter of 4 mm) was laminar flow and it was unstable flow regime for sand-filled dripper of types 6 and 10 (SFD diameter of 6 and 10 mm respectively). (2) The discharge rate of all types of SFDs increases with the increase in the operating pressure. (3) The coefficient of variation (C_V) for SFDs was decreased with increasing the working pressure, while the emission uniformity (EU) for all types of SFD was increased with increasing the operating pressure. This means that there is an inverse relationship between the coefficient of variation and the emission uniformity, where the emission uniformity decreases with an increase in the coefficient of variation. (4) The dripper flow variation (q_{var}) for all SFDs was less than 25% that is in an acceptable range.

Finally, this paper is a new research idea, and a new method may be solving the emitter clogging problem in drip irrigation network, where the results research has created an important experimental data that can be used as a basis for maximizing the performance efficiency of drip irrigation systems in order to manage the irrigation water more efficiently. Also, the results of this research can be used as a reference to improvement, promotion, and application of sand-filled drippers in drip irrigation networks. In addition, the different field experiments will be conducted in the future to irrigate some crops using the drip irrigation system using sand-filled drippers to compare these with conventional online drippers, as well as to find out the distribution pattern of irrigation water in the soil under SFD.

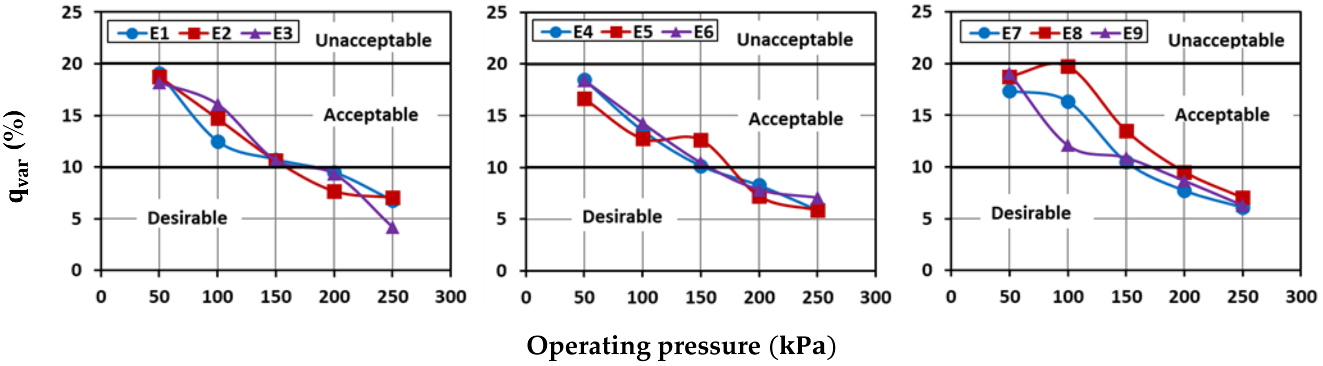


Fig. 12. The experimental data and the relationships between flow variation "q_{var}" (%) and working pressure "P" (kPa) for type 4 of SFD.

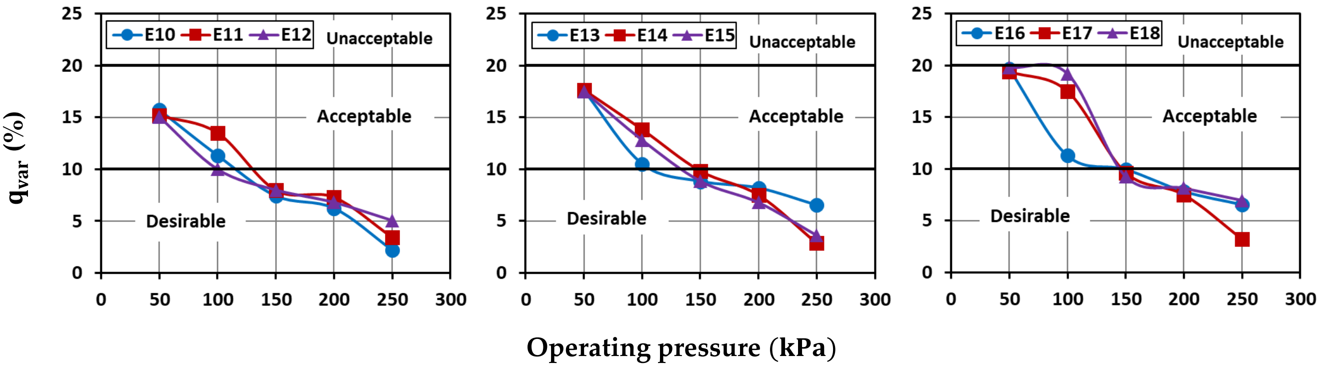


Fig. 13. The experimental data and the relationships between flow variation "q_{var}" (%) and working pressure "P" (kPa) for type 6 of SFD.

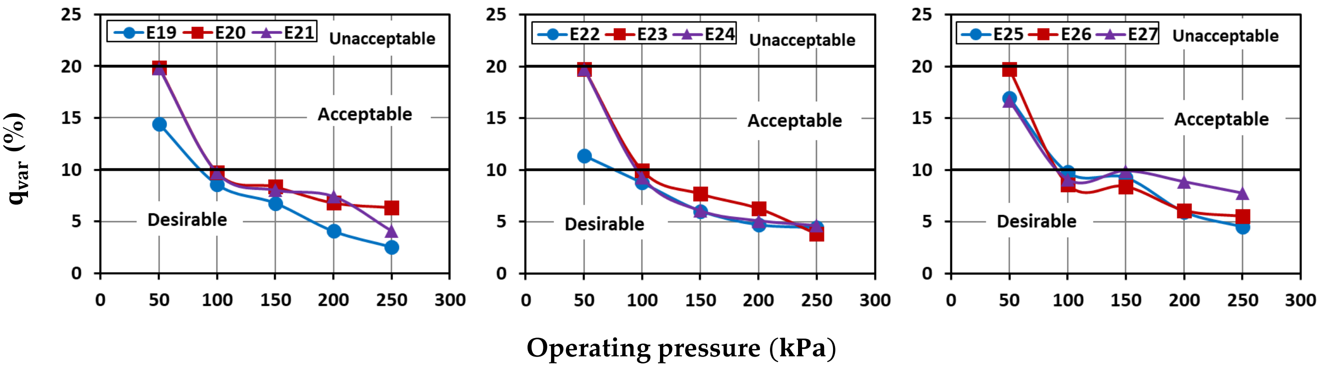


Fig. 14. The experimental data and the relationships between flow variation "q_{var}" (%) and working pressure "P" (kPa) for type 10 of SFD.

Table 8

A classification summary of the three types of sand-filled drippers at different operating pressures "P" (kPa) based on flow variation according to the recommended classification of Wu and Gitlin (1983).

Type of SFD (SFD code)	Operating pressure "P" (kPa)				
	50	100	150	200	250
	Classification based on q_{var}				
Type 4 (E1, E2, … and E9)	Acceptable	Acceptable	Acceptable	Desirable	Desirable
Type 6 (E10, E11, … and E18)	Acceptable	Acceptable	Desirable	Desirable	Desirable
Type 10 (E19, E20, … and E27)	Acceptable	Desirable	Desirable	Desirable	Desirable

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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تقييم الآداء الهيدروليكي لمنقط محشو بالرمل

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الملخص العربي

المنقط المحشو بالرمل أو المنقط الرملي هو نقاط جديد يستخدم لإضافة مياه الري للتربة من خلال شبكة الري بالتنقيط، وهو عبارة عن أنبوبة من البولي ايثلين مملوءة بحبيبات رمل متجانسة القطر ومغلقة من أحد طرفيها بقطعة من سلك غربال للسماح بخروج المياه مع تركيب بداية خط في النهاية الأخرى حتى يمكن من خلالها تركيب المنقط في خط التنقيط في شبكة الري بالتنقيط.

وتهدف هذه الدراسة إلى معرفة تصرف المنقط الرملي عند ضغوط تشغيل مختلفة تقييم آداء المنقط الرملي هيدروليكياً ومعرفة الخصائص الهيدروليكية المختلفة له. **وكانت متغيرات الدراسة كما يلي:**

(١) ثلاثة أقطار لأنبوبة المنقط هي ٤ و٦ و ١٠ مم.

(٢) ثلاثة أطوال للمنقط هي ١٠ ، ١٥ و ٢٠ سم.

(٣) ثلاثة أقطار لحبيبات الرمل المتجانس والمعبأ بها المنقط هي: ١ و٠,٨ و٠,٢ مم.

(٤) خمسة ضغوط تشغيل هي ٥٠ و ١٠٠ و ١٥٠ و ٢٠٠ و ٢٥٠ كيلو باسكال.

ووفقاً لمتغيرات الدراسة السابقة، تم تصنيف المنقطات الرملية حسب قطر أنبوبة المنقط إلى ثلاثة أنواع هي النوع ٤ والنوع ٦ والنوع ١٠، كل نوع يندرج تحته ٩ منقطات مختلفة وبالتالي تم انتاج ٢٧ منقط كل منها له مواصفاته التقنية الخاصة.

تم تشغيل المنقطات في شبكة ري بالتنقيط عند ضغوط التشغيل المختلفة وتجميع المياه المتصرفة من منها وحساب كل من تصرف المنقطات الرملية عند ضغوط التشغيل المختلفة واستنتاج معادلة تصرف المنقطات الرملية وكذا حساب معامل الاختلاف التصنيعي وانتظامية التوزيع ومعامل اختلاف السريان. **وكانت أهم النتائج المتحصل عليها كما يلي:**

- معدل تصرف المنقطات الرملية كان يزداد بزيادة ضغط التشغيل وبالتالي كانت العلاقة بين ضغط التشغيل وتصرف المنقط الرملي تُمَثل بدالة قوى وكان نوع السريان رقائقي Laminar flow للمنقطات الرملية من النوع ٤ أما بالنسبة للمنقطات الرملية من النوعين ٦ و ١٠ فكان السريان غير مستقر Unstable flow regime.
- معامل الاختلاف التصنيعي للمنقطات كان يقل بزيادة التصرف وبالتالي كان تصنيف المنقطات الرملية حسب معامل الاختلاف التصنيعي جيد Good عند ضغوط تشغيل ٢٠٠ و ٢٥٠ كيلو باسكال بالنسبة للمنقطات الرملية من النوع ٤، أما بالنسبة للمنقطات الرملية من النوعين ٦ و ١٠ فكان التصنيف جيد Good عند ضغوط تشغيل ١٥٠ و ٢٠٠ و ٢٥٠ كيلو باسكال وذلك وفقاً لتوصيات منظمة ISO الدولية للتوحيد القياسي (ISO 1990).
- انتظامية التوزيع للمنقطات كانت تزداد بزيادة التصرف وبالتالي كان تصنيف المنقطات الرملية حسب انتظامية التوزيع ممتاز Excellent عند ضغوط تشغيل ١٥٠ و ٢٠٠ و ٢٥٠ كيلو باسكال بالنسبة للمنقطات الرملية من النوعين ٤، ٦ أما بالنسبة للمنقطات الرملية من النوع ١٠ فكان التصنيف جيد Excellent عند ضغوط تشغيل ١٠٠ و ١٥٠ و ٢٠٠ و ٢٥٠ كيلو باسكال وذلك وفقاً لتوصيات الجمعية الأمريكية للهندسة الزراعية (ASAE, 1999).
- معامل اختلاف السريان لجميع المنقطات الرملية (الأنواع الثلاثة ٤ و ٦ و ١٠) كان دائماً أقل من ٢٥٪ في الحدود المسموح بها وفقاً لتوصيات Wu and Gitlin (1983).

وأخيراً يمكن القول إن هذه الدراسة هي فكرة بحثية جديدة خلقت نتائجها بيانات تجريبية مهمة يمكن استخدامها كأساس لتعظيم كفاءة أداء أنظمة الري بالتنقيط من أجل إدارة مياه الري بشكل أكثر كفاءة. كما يمكن استخدام نتائج هذا البحث كمرجع لتحسين وتعزيز وتطبيق المنقطات الرملية في شبكات الري بالتنقيط. بالإضافة إلى ذلك، سيتم إجراء تجارب حقلية مختلفة في المستقبل لري بعض المحاصيل بنظام الري بالتنقيط باستخدام المنقطات الرملية لمقارنتها بالمنقطات التقليدية المتعارف عليها، وكذلك لدراسة انتشار وشكل توزيع مياه الري في التربة تحت المنقطات الرملية.