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El-Gindy A.M.

Agriculture Engineering, Ain Shams, Univ. Dokki, Cairo, Egypt

K. F. El-Bagoury

Agriculture Engineering, Ain Shams, Univ. Dokki, Cairo, Egypt

Ebtisam I. Eldardiry

Water Relations and Field Irrigation Dept. National Research Centre, El-Buhouth St., Dokki, Cairo, Egypt

M. Abd El Hady

Water Relations and Field Irrigation Dept. National Research Centre, El-Buhouth St., Dokki, Cairo, Egypt

Rania A. Elkersh

Water Relations and Field Irrigation Dept. National Research Centre, El-Buhouth St., Dokki, Cairo, Egypt

Correspondence:

Ebtisam I. Eldardiry

Water Relations and Field Irrigation Dept. National Research Centre, El-Buhouth St., Dokki, Cairo, Egypt

Hydraulic Studies of Drip Irrigation System under Using Low Quality Water Conditions I- Application efficiency, Uniformity Coefficient and Coefficient of Variation of the examined emitters.

El-Gindy A.M., K. F. El-Bagoury, Ebtisam I. Eldardiry, M. Abd El-Hady, Rania A. Elkersh

Abstract

Water characteristics have the majority effect on the hydraulic performance of on-farm irrigation systems and their equipment. Therefore, the aim of this study was to evaluate the hydraulic characterization of surface drip irrigation system and its emitters under saline-water conditions. Hereby, laboratory experiment was carried out at water Relations and Field Irrigation Dept., (NRC) to evaluate hydraulic performance of five emitter types. Lab experiments were conducted to evaluate hydraulic parameters for five emitter types [Non pressure compensating 1emitter (NPC1), Non pressure compensating 2 emitter (NPC2), Non pressure compensating 3 emitter (NPC3), pressure compensating emitter (PC), and Pressure compensating and Self-flushing emitter (PCS)] under water salinity (345, 2000, 4000, 6000; 8000 ppm) and different operation pressure heads (0.8, 1.0, 1.2, 1.4, 1.6, 1.8; 2 bar). Results showed that using NPC1, NPC2 and NPC3 under water salinity 345, 2000 and 4000 ppm were better in uniformity coefficient, manufacture variation, and clogging ratio. It could be concluded that emitter types of NPC1, NPC2, and NPC3 under using water salinity 345, 2000, and 4000 ppm were the best and could be recommended to apply in the field research work. There are no significant differences between PC, PCS, NPC1, NPC2 and NPC3 in this concern so, the emitters NPC1, NPC2, and NPC3 are recommended to use in field experiment.

Keywords: Hydraulic, uniformity coefficient coefficient of variation, emitter type, water salinity

Introduction

Salinity is the salt content in water, which is expressed by electrical conductivity (EC), and commonly referred to EC in laboratory analyses (Western Fertilizer Handbook, 2002). Drip irrigation is the slow, deep, and regular application of water directly to the root zone of your plants. This method of irrigation requires 30-70% less water than conventional sprinklers by providing water directly to the plants and reducing waste from runoff and evaporation. The water flows at a low pressure through polyethylene pipes or soaker hoses laid in rows or serving groupings of plants. The water slowly enters the soil from emitters, pre-punched holes or porous pipe. Drip irrigation is used to water everything from annuals in pots to full-scale fruit orchards. Meanwhile, Amosson et al., (2002) reported that drip irrigation has gained widespread popularity as an efficient and economically viable method because of its highly localized application and the flexibility in scheduling water and chemical applications. When using low-quality water, drip irrigation has several advantages over other irrigation methods; e.g., possible damage to the foliage is prevented and because of salts accumulation at the wetting front soil salinity (EC) in the root zone is similar to the initial salinity in the irrigation water (Sanij et al., 2004) when the irrigation is managed properly. Whereas, if management is not properly practiced, irrigation with low-quality water can compound existing problems with soil salinity, and in some cases, EC in the root zone can reach levels that can be toxic to crops. Drip irrigation is the most effective method for wastewater reuse, but the suspended solids and organic matter contained in wastewater can lead to a high risk

of system failure due to clogging of the drippers and filtering difficulties. The clogging of drip emitters is the largest maintenance problem with drip systems (Keller and Bliessner, 1990). It is difficult to detect and expensive to clean or replace clogged emitters. Partial or complete clogging reduces emission uniformity and as a consequence decreases irrigation efficiency (Capra and Scicolone, 2004). Clogging causes the poor distribution of water between the plants. In technical terms, it reduces emission uniformity. Emission uniformity is not a parameter of efficiency, but it is not possible to have high efficiency when emission uniformity is low. In these conditions, to assure that all plants receive their water requirement, the water volumes needed for crop growing increase. Over-irrigation caused deep percolation and consequent disadvantages, due to energy costs, fertilizer leaching, drainage needs and groundwater contamination risk.

Material and Methods

Laboratory experiments were carried out at the department of water relations and field irrigation, National Research Centre (NRC), El-Dokki, Cairo, Egypt. Five saline water degrees having different salinity (EC) (345, 2000, 4000, 6000 and 8000 ppm) (0.52, 3.13, 6.25, 9.043 and 12.052 dS m⁻¹) were used. With Five types of emitters [Non pressure compensating 1emitter (NPC1), Non pressure compensating 2 emitter (NPC2), Non pressure compensating 3 emitter (NPC3), pressure compensating

emitter (PC), and Pressure compensating and Self-flushing emitter (PCS)] under different pressure head levels 0.8, 1.0, 1.2, 1.4, 1.6, 1.8 and 2 bar. With discharge rate 4 l/h were used. The experiment was laid out in factorial RCB design with three repetitions. Irrigation water of desired salinity levels were prepared by mixing canal water (EC=345 ppm) with underground water (EC= 4000 ppm) and stored in plastic tank of 1000 liters capacity.

Emitter discharge was measured (volumetrically and triplicated) over a range of seven pressures (0.8, 1.0, 1.2, 1.4, 1.6, 1.8, and 2 bar) to determine the manufacturing variation of each type. A stopwatch was used to measure the flow times. The water volumes were collected in the graduated cylinders and manually read and recorded.

The experimental layout

The lab study used a laboratory-scale apparatus fitted with two laterals of PE drip tubing, each 15 m in length. Each lateral contains 50 emitters (4 l/h) with a space of 30 cm. five types of emitters were used as shown in Table (1). Water was supplied to the laterals from a Polyethylene, 500L (0.5 m³) supply tank using a 373-watt (0.5hp), high head pump. Additionally, a flow meter was installed to record the total volume of water supplied to the system. The pressure in the laterals was regulated by a two bar regulator installed after the pump. One-liter measuring cylinders with 10 mL divisions were used to collect the water from the emitters as shown in Figure (1).

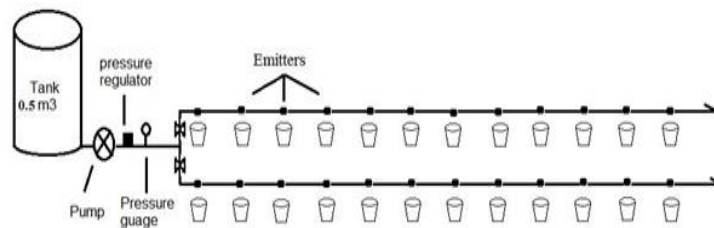


Fig. 1: lab experiment layout.

Table (1): Manufacturer’s parameters of selected drip emitters

Emitter model	Emitter type	Nominal flow rate (L/hr @ Kpa)	Recommended operating pressure (Kpa)
NEIN-ETF	NPC1 PS	3.90 @ 137.9	68.9 – 310.3
GR	NPC2 LS	3.79 @ 167.9	48.3 – 413.7
NEIN ENEIN-PC	PC PS	3.785 @ 172.37	68.95 – 413.7
EDEN NEIN- PC	PCS PS	3.785 @ 172.37	68.95 – 413.7
KATIF Rivulis Plastro	NPC3	4.00 @ 206.84	68.95 – 413.7

PC: Pressure compensating, NPC: Non pressure compensating, PCS: Pressure compensating and Self-flushing, LS = Line source, PS = Point source.

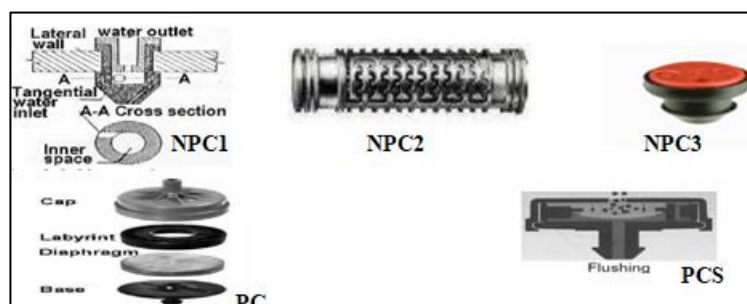


Fig. 2: Some of the tested emitters.

Performance and evaluation of the selected emitters

During the test, water temperature was measured by a digital thermometer with a precision of ± 1.0°C to account for viscosity changes. Specific emitter flow functions, such as pressure flow relationship and manufacture coefficient, were determined. These tests were conducted at a water temperature of (20 -23)°C. for point source and line source devices, the flow rate determination was calculated per outlet.

The pressure influence on emitter flow rate can be presented in two ways, either directly as the average of emitter flow rate or as a percentage of flow rate change that occurred at the actual operating pressure and pressure of 1 bar with the same water temperature, divided by the flow rate at pressure of 1 bar according to (Keller and Karmeli, 1974) as follows:

$$= \frac{q}{q_{100}} \times 100 \dots\dots\dots (1)$$

where

q var: the emitter flow variation

qmax: the maximum emitter flow along the lateral line, l/h, and

qmin: the minimum emitter flow along the lateral line, l/h.

Emitters discharge

A numerical method to measure the desirability of pressure, flow characteristics for a given emitter device is based on a flow rate vs. pressure curve (Q-H) fitted to an equation of the following

$$\text{form: } Q=k H^x \dots\dots\dots (2)$$

Where: Q is the emitter flow rate, m³/sec; k is the emitter Coefficient, 1/sec; H is the pressure head in the lateral at the location of emitters, m; and x is the exponent characteristics of emitters, unit less.

Exponent x is an indication of the flow regime and emitter type. It is an indirect measure of the sensitivity of flow rate to the change in pressure. The value of x typically ranges between 0-1.0, where a lower value indicates a lower sensitivity and a higher value indicates a higher sensitivity. For PC emitters the value should be less than 0.1 and should approach 0. For NPC emitters, it should approach 0.5 (Cuenca, 1989).

Table (2): Emitter exponent values for various emitters (ASAE, 1985)

Flow regime	Exponent x	Emitter type
Variable flow path	> 0.1	Fully pressure compensating ↑↓
	0.1	
	0.2	
	0.3	
Vertical flow	0.4	Partially pressure compensating
Fully turbulent flow	0.5	Non-pressure compensating ↑↓ Fully non-pressure compensating
Mostly turbulent flow	0.6	
	0.7	
Mostly laminar flow	0.8	
	0.9	
Fully laminar flow	1.0	

Manufacturing coefficient of variation

The coefficient of variation (CV) is defined as the ratio of standard deviations of the discharges (Madramooto, 1988). In the lateral design, emitter flow variation is used as a design criterion. The emitter flow variation comprises hydraulic variation and due to manufacturing variation among the emitters. The latter depends on the quality control in production. The unit to unit variation in the

emitter flow was expressed by the following relationship:

$$CV = \frac{S}{q} \times 100 \dots\dots\dots (3)$$

Where: CV: manufacturing coefficient of variation, S: sample standard deviation, and q: average emission rate of the sample.

Table 3: Micro-irrigation system uniformity classification based on the coefficient of variation Emitter type

Point-source		Line source	
Cv range	Classification	Cv range	Classification
< 0.05	Excellent	< 0.10	Good
0.05 - 0.07	Average	0.10 – 0.20	Average
0.07 - 0.11	Marginal	>0.20	Marginal to Unacceptable
0.11 – 0.15	Poor		
>0.15	Unacceptable		

ASABE Standards EP405.1, 2008R

The standard deviation of emitter flow rate, Sq, (ASABE, 2008R) can be written as:

$$S = \sqrt{\frac{\sum (q - \bar{q})^2}{n}} \dots\dots\dots (4)$$

The coefficient of manufacture variable measures the

variation in flow rate for a given emitter model at a normal operation pressure ranging from 0.2 to 2.0 bar and a water temperature of (20-23°C).The emitter manufacture's coefficient of variation "CV" is one of the statically terms, which can be used to show the drip irrigation system uniformly.

Distribution Uniformity

The distribution uniformity (DU) of water was computed along a lateral for five emitters under pressures range of 0.8, 1.0, 1.2, and 1.4 bar of pressure head. First, the emission from each emitter was calculated for a particular length of lateral using the methodology stated above. Then the average flow was determined for all emitters. After that, the average flow of the lowest quartile was determined and

for a particular product for various lateral lengths, the distribution uniformity was calculated as:

$$DU=100 \left(\frac{q_m}{q_a} \right) \dots\dots\dots (5)$$

Where DU = distribution uniformity, %; q_m = the average flow rate of the emitters in the lowest quartile, m^3/s ; and q_a = the average flow rate of all emitters under test, m^3/s .

Table 4: Micro-irrigation system uniformity classification based on uniformity coefficient

Uniformity coefficient %	UC %
Above 90	Excellent
90-80	Good
80-70	Fair
70-60	Poor
Below 60	Unacceptable

ASAE Standards EP 458(1999)

Variability in the flow rate depends on the pressure regime, the manufacturing variance of the emitter and partial emitter clogging.

Emitters Clogging

To estimate the emitter flow rate cans and a stopwatch was used. Nine emitters from each lateral had been chosen to be evaluated by calculating their clogging ratio at the beginning and at the end of the growing season for two seasons. Three emitters at the beginning, three at middle and three at the end of the lateral were tested for flow rate. Clogging ratio was calculated after (El-Berry *et al.*, 2003) using the following equations:

$$E = q_u / q_n * 100 \dots\dots\dots (6)$$

$$CR = (1 - E) 100 \dots\dots\dots (7)$$

Where

- E = the emitter discharge efficiency (%)
- q_u = emitter discharge, at the end of the growing season (L/h)
- q_n = emitter discharge, at the beginning of the growing season (L/h)
- CR = the emitter clogging ratio (%)

Statistical analysis:

The data were subjected to the analysis of variance (ANOVA) appropriate to the randomized complete block design applied after testing the homogeneity of error variances according to the procedure out-lined by

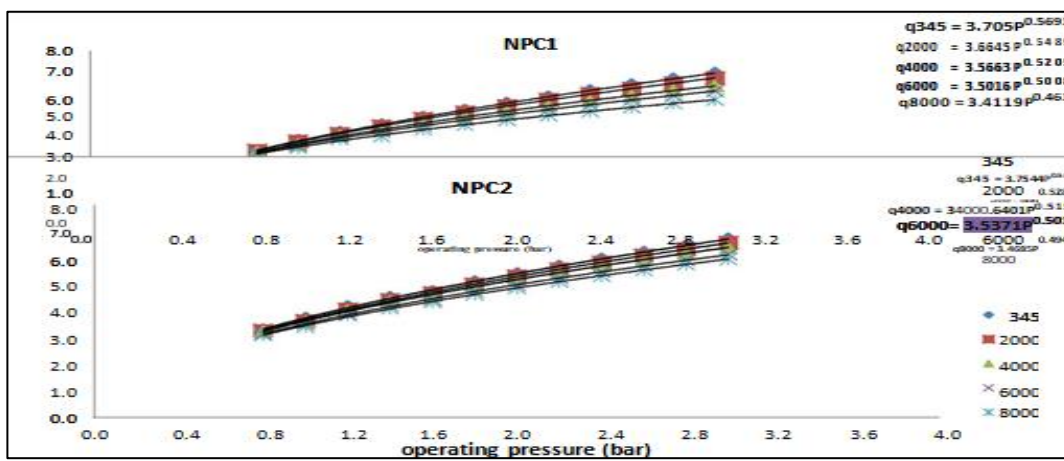
Dospekhov (1984). The significant differences (LSD) between treatments were compared with the critical difference at 5% probability level.

Results and Discussion

Calibration of emitters

It is known that, in a drip irrigation system, there is a positive relationship between the operating pressure and the emitter flow rate. This relationship may be affected by some changes in the physical properties of water; one of these changes increases the proportion of salt, which exists in low-quality water. Figure (3) illustrates the relation between the emitter flow rates with water salinity and/or operation pressure.

Regarding the effect of operation pressure on the flow rate of the different studied emitters NPC1, NPC2, PC, PCS, and NPC3, one can notice that increasing operation pressure associated with increase emitters flow rate. Meanwhile, the lowest flow rate value (3.27 l/h) was obtained from PCS at 0.8 bar and the highest one was recorded after operation pressure 1.6 bar (4.26 l/h) from NPC1 emitter. Additionally, PCS followed by NPC3 scored the lowest flow rate 3.61 and 3.99 l/h, respectively. While the other tested emitters, it could be arranged in descending order relative to the flow rate NPC1> PC> PCS>NPC3>NPC2. Also, it is worthy to mention that the rate of increase flow rate as affected by operation pressure were 4, 9, 14 – 3, 5, 8 and 3, 5, 9 % in same sequences, if we compare the emitter flow rate at 1, 2; 1.4 bar comparing with 0.8 bar.



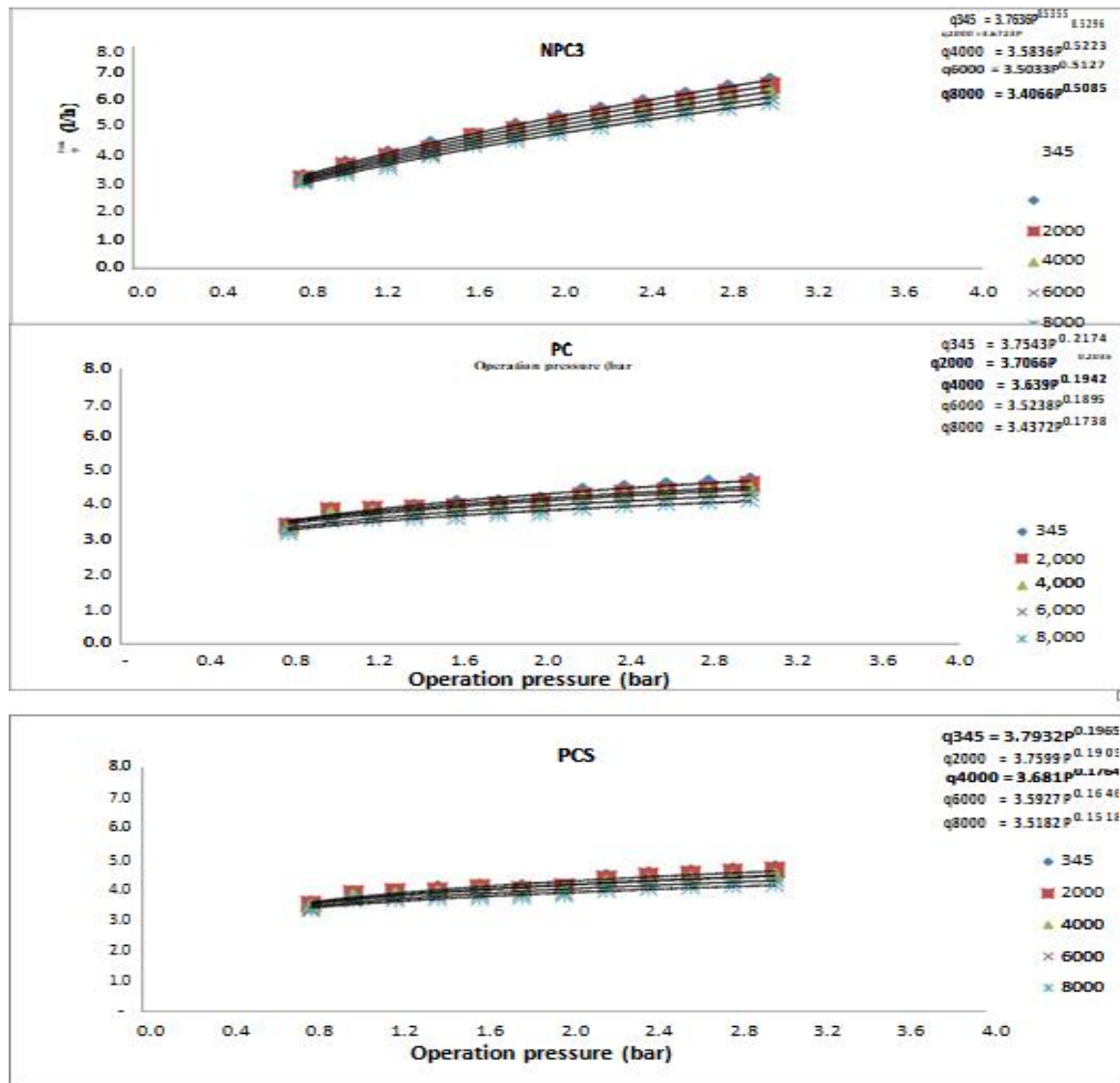


Fig. 3: Effect of water salinity on emitters flow rate.

With respect to the water salinity and its effect on the flow rate of the examined emitters, Figure (3) illustrated that PCS and PC were the worthy ones that dramatically decreases their flow rate with increasing water salinity. From the other side, NPC1 and NPC3 were the most suitable and moderately affected by water salinity followed by NPC2. The maximum and minimum numbers of the flow rate of the tested emitters were obtained after canal water and 8000 ppm saline water.

From the above mentioned, it is clear to point out that emitter named NPC1 followed by NPC2 and lastly NPC3 were not affected strongly by increasing water salinity. Our data was in agreement with those obtained by Almajeed and Alabas (2013), who stated that the main problem is the drop in pressures and discharges distribution in the network resulting from the amount of pressure losses between the head of the lateral as compared with that in the end of the lateral, which affects the discharge distribution of emitters and uniformity.

Manufacturing coefficient of variation for testing emitter types:

Regarding to the coefficient of variation (CV) as affected by emitter's type and operating pressure, Figure (4) demonstrated that the rank of emitter types can be written in the following ascending order: NPC1 < NPC2 < NPC3 < PC < PCS. In addition, data can also notice that there are no significant differences between PC, PCS, NPC1, NPC2 and NPC3 in this concern. Results showed that emitters NPC1, NPC2, and NPC3 are recommended to use in field experiment. Resulted data are in agreement with those obtained by Solomon (1979) and Bozkurt & Ozekici, (2006) mentioned that the efficiency of drip irrigation systems depends on the uniformity of emission rates throughout the system. An important factor affecting this uniformity is the unit-to-unit variation between emitters. The design of an emitter, the materials from which it is made, and the cares taken in the manufacturing processes affect the amount of such unit-to-unit variation that may be expected.

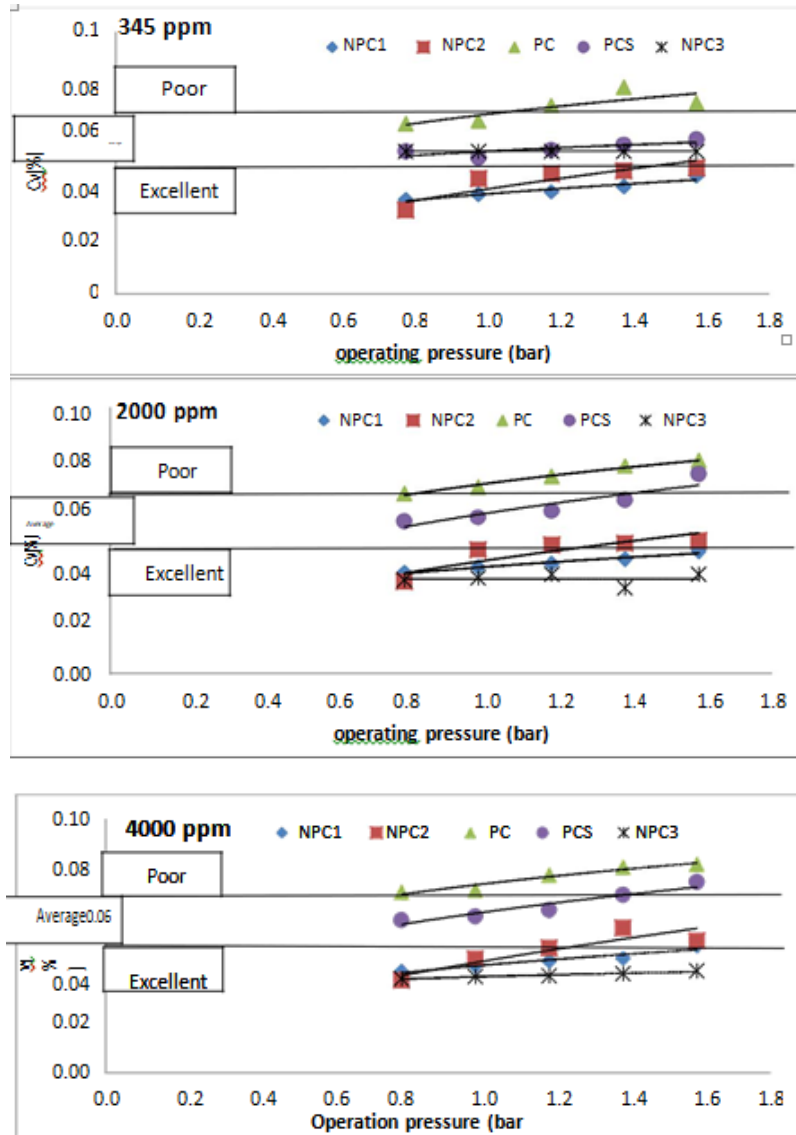


Fig.4: a: Effect of emitter type on the coefficient of variation (CV) under different pressure head.

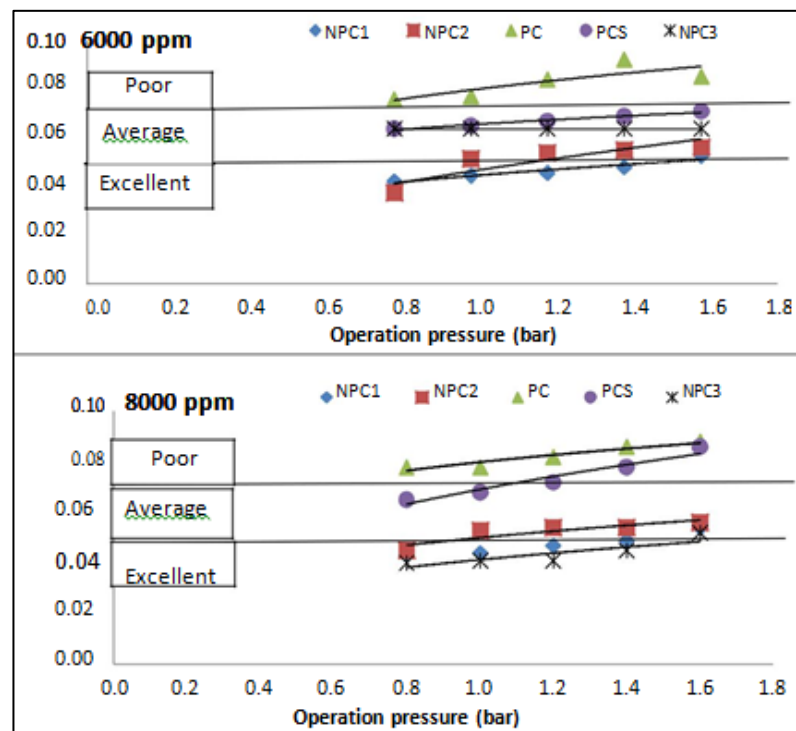


Fig. 4: b: Effect of emitter type on the coefficient of variation (CV) under different pressure head.

Effect of water salinity on emitter's clogging

In order to study the clogging behavior of emitters of the same discharge rates as influenced by different irrigation water salinity levels on clogging percentage, clogging ratio for emitters are presented in table (5). Clogging of emitters was found to increase with an increase in salinity of the water. In the present study, water used for irrigation was having EC values ranging from 345 to 8000 ppm. In higher EC water, the content of cations viz. Ca and Mg and anions viz. SO₄, CO₃, and HCO₃ were more than the waters with lower salinity. When Ca, Mg and Na combine with SO₄, CO₃ or HCO₃ then some of these combinations form insoluble or sparingly soluble salts cause's drippers clogging. The composition of deposited salts in lateral also supports this finding. As discussed earlier that there was a positive relationship between uniformity coefficient and clogging percentage. Use of higher salinity water resulted in higher clogging percentage which ultimately leads to

poor uniformity coefficient. Dripper clogging affected distribution uniformity and the system performance which had a direct relationship with water quality and the coefficient of final variation increased with the dripper clogging. The highest clogging ratio was at PC and PCS emitters, so they weren't recommended to use in field experiments. These results were in line with those obtained by Ribera et al., (2004) and Quanli Zong et al., (2015). They stated that the clogging of drip emitters is the largest maintenance problem with drip irrigation systems whilst Capra and Scicolone (2004) reported that water quality is a major concern in the management of trickle irrigation systems. Emitters plugged by physical, chemical, or biological contaminants may create significant problems in everyday maintenance. Therefore, effective and reliable filtration is mandatory for successful operation of trickle irrigation systems (Haman and Zazueta, 2017).

Table 5: The effect of different emitter types and saline water on clogging percent

Water Salinity	Clogging ratio (%)				
	NPC1	NPC2	PC	PCS	NPC3
345	9.58	8.36	20.45	21.36	9.33
2000	10.47	10.75	24.36	22.54	10.25
4000	11.23	11.37	26.41	24.52	11.46
6000	20.54	21.64	28.36	27.8	21.36
8000	22.65	22.35	29.56	26.35	23.75

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