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PERFORMANCE EVALUATION OF LOW HEAD BUBBLER IRRIGATION SYSTEM

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ABSTRACT

The aim of this research was to investigate the performance of three bubbler tube diameters at three initial operating pressure of 15, 30, 45 *kPa* to determine optimum operating conditions that achieve high discharge uniformity *Cu*. The coefficient of uniformity (*Cu*) was evaluated in two cases. First, when bubbler outlets heights were at the same level at 0.0, 0.2, 0.4, 0.6, 0.8 and 1.0 *m*. The results show that the highest values of the coefficient of uniformity were obtained from initial operating pressure of 30 *kPa* and internal bubbler tube diameters of 5.2 *mm* where values were almost constant with average 99.3%. Second, when bubbler outlets were parallel to the hydraulic gradient line with three effective heads for each initial operating pressure. The results show that all bubbler tubes along the lateral line give the same discharge for *ID* 3.8 and 5.2 *mm*, but the discharge different for 13.6 *mm* bubbler tube diameter.

The recommended bubbler diameter was 5.2 *mm* at 30 *kPa* initial operating pressure to achieve high discharge uniformity; In addition, it achieves higher lateral line length than 3.8 *mm* bubbler diameter to minimize initial irrigation system cost. Also, bubbler diameters 13.6 *mm* are not recommended for low-head bubbler systems due to poor water distribution uniformity.

INTRODUCTION

Bubbler irrigation is one of the microirrigation systems which have many advantages. Water and energy savings are the most important advantage which is smaller than other irrigation systems. Capital cost and maintenance requirements are low. Microirrigation achieves higher irrigation efficiency and higher yields than other irrigation systems. Two major types of bubbler irrigation systems are available low and high pressurized systems. The low head bubbler systems are based on gravity flow (about 10 to 50 *kPa*) and pressurized (50 to 150 *kPa*) systems. Hull (1981) stated that bubbler system is restricted to slope of (1-3%).

Yitayew *et al*., (1995) mentioned that the distinguishing feature of low-head bubbler systems is the flexible delivery hoses. Water distributed to the bubbler tubes by adjusting the elevations of the tube outlets along the lateral so that water flows out from all hoses at approximately equal rates.

Water is applied to the soil surface from bubbler irrigation as a little stream, typically from a small diameter tube (1 *mm* to 13 *mm*) or a commercially available emitter. Because the application rates generally exceed the soil infiltration rates, small basins or furrows are needed to control the water distribution on the land Lamm *et al*. (2007). Despite this early experimental success, the bubbler concept has not been widely adopted in agriculture. Perhaps one of the main reasons for the lack of interest is that design criteria and recommended operating procedures have not been readily available.

Hydraulic performance evaluation which is used to determine and verify the characteristics of the bubbler systems can be determined on the basis of parameters, such as Coefficient of Manufacturing variation (*Cv)*, Coefficient of uniformity (*Cu*) and (*k*, *x*) parameters. The key to efficient irrigation is Coefficient of uniformity. Irrigation system performance can be expressed in terms of the determined Coefficient of Manufacturing variation and Coefficient of uniformity. The more uniformly water is applied, potentially the more efficient the irrigation.

Lamm *et al*., (2007) mentioned that the manufacturer's coefficient of variation for five models tested ranged from 8 to 21 %, which is relatively high for microirrigation emitters. ASAE Standards (2000) recommends values less than 11% and suggests that values greater than 15 % are unacceptable.

Habib and Awady (1992) stated that the discharge uniformity from bubbler irrigation system is controlled by varying the tube diameter and/ or length and/ or using valve for each bubbler along lateral line.

Nakayama and bucks (1986) studied the relationship between emitter flow variation and uniformity coefficient and reported that a uniformity coefficient of a bout (98%) equal an emitter flow variation of (10%) and a uniformity coefficient of about (95%) equals an emitter flow variation of (20%). Benami and Ofen (1984) stated that for practical purpose it is recommended that allowable variation in pressure head be limited to (15%) for lateral line design in drip irrigation system.

Due to the lack of well defined design procedure for bubbler irrigation system and difficulties associated with the change of bubbler outlet height along lateral line. The aim of this study was evaluate the effect of different pressures and bubbler diameters on bubbler discharge uniformity when bubbler outlet heights at the same level and parallel to the hydraulic gradient line.

MATERIALS AND METHODS

The experimental work was conducted at the farm of Agriculture Faculty, Suez Canal University. The experimental bubbler irrigation system shown in figure (1) can be described as follows: The water is pumped from the water source by using centrifugal pump self priming, suction-orifices diameter: 38.1 *mm* and delivery-orifices diameter: 31.8 *mm* which powered by electric motor 2.2 KW, 220 volts. The water is pumped to a cylindrical plastic tank with dimensions; height 0.9 *m*, diameter 0.49 *m* with 0.17 m^3 capacity. The water level was kept constant in the tank by using an over flow tube with diameter 50 *mm*. The main pipe branched to two sub main pipes with one lateral mounted in each one. Two valves mounted on entrance and end of each lateral to control and flushing the air from it. The lateral pipe was a smooth polyethylene with 30 *m* length and nominal diameter 32 mm (*ID*, 28 mm internal diameter).

The lateral pipe slope is zero. Five delivery tubes (bubblers) mounted on each lateral pipe with 6 *m* space between them. The bubbler tubes were smooth polyethylene with nominal diameter 4.5, 6 and 16 *mm* and *ID* (3.8, 5.2, 13.6 *mm*) respectively, the length of each bubbler was 5 *m* as shown in figure (1).

The bubbler was tide to wooden stakes substituted of tree trunk. Pressure gauges were mounted before each bubbler inlet to measure the pressure.

The bubbler discharge characteristics are usually characterized by the relationship between discharge, pressure and a bubbler discharge exponent. The equation for bubbler flow can be expressed as:

$$q = k\,h^{x} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad 1$$

Where:

q: The bubbler discharge rate, ℓ/h,

k: Dimensionless constant of proportionality that characterizes each bubbler.

h: Pressure head at the bubbler, *m* and

x: Dimensionless bubbler discharge exponent that is characterized by the flow regime. It measure how sensitive the bubbler discharge is to the pressure as shown in table (1).

Table (1): Recommended classification of flow regime according to the value of *x*

x	Classification*
0.00	fully pressure compensating
0.25	partially pressure compensating
0.50	fully turbulent flow regime
0.75	partially turbulent or unstable flow regime
1.00	laminar flow regime

*** according to (Howell and Hiler, 1972; Wu and Gitlin, 1973; Howell and Hiler, 1974; Karmeli, 1977; Solomon and Bezdek, 1980; Braud and Soon, 1981 and Boswell, 1985).**

The manufacturer's coefficient of variation *Cv* was calculated for used bubbler inside diameters 3.8, 5.2 and 13.6 *mm* by measuring the bubbler discharge as follow, ASABE Standards (2006):

$$Cv = \frac{s}{\bar{x}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad 2$$

Where:

Cv: Manufacturer's coefficient of variation (Dimensionless)

S : The standard deviation of bubbler discharge (ℓ/h) in the sample was determined according to equation (3) and

$\bar{x}$: The mean discharge of bubblers, ℓ/h.

$$s = \left[\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n-1}\right]^{1/2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad 3$$

x_i: The discharge of an bubbler

n: The number of bubblers.

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ASABE Standards (2006) classified emitters based on coefficient of manufacturer's variation *Cv*. Table (2) illustrates the recommended classification of (*Cv*) for point source emitter as indicated.

Table (2): Recommended classification of manufacturer's coefficient of variation (*Cv*), according to ASABE Standards (2006).

***Cv* range**	**Classification**
< 0.05	Excellent
0.05 to 0.07	Average
0.07 to 0.11	Marginal
0.11 to 0.15	Poor
>0.15	unacceptable

The (*Cu*) is a better way of expressing the variation discharge on lateral line. The uniformity coefficient (*Cu*) was calculating by Perold (1977) bubbler irrigation system equation as follows:

$$Cu\ (\%) = \left(1 - |\overline{\sigma}|\right) \times 100 \quad \ldots\ldots\ldots\ldots\ldots \quad 4$$

Where:

Cu: Coefficient of uniformity, % and

$|\overline{\sigma}|$: Absolute mean deviation of discharge on lateral line. it calculated by using the formula:

$$\overline{\sigma} = \frac{\sum\left(q - \overline{q}\right)}{n} \quad \ldots\ldots\ldots\ldots\ldots \quad 5$$

Where:

n: Number of bubblers

$\overline{q}$: Bubblers discharge mean, ℓ/s and

q: The discharge from bubbler, ℓ/s.

The results were compared to the ASAE Standards (1999) field microirrigation performance standards. The general performance evaluation criteria for (*EU*) values are: >90%, excellent; 80–90%, good; 70–80%, fair; and <70%, poor.

RESULTS AND DISCUSSION

The results displayed bubbler hydraulic performance for three bubbler tube diameters in state of bubbler outlet heights at the same level or changeable according to the following order:

- Effect of pressure on bubbler discharge, bubbler discharge equation constants (k, χ).
- Manufacturer's coefficient of variation (*Cv*).
- Discharge uniformity coefficient (*Cu*)

Effect of operating pressure on discharge

The effect of operating pressure on discharge for three bubbler diameters 3.8, 5.2 and 13.6 *mm*, is presented in table (3) and Figure (2).

Bubbler discharge proportionally increased with increasing the operating pressure for all bubbler tube diameters. Due to increasing the operating head from 1.1 to 2.0 *m*, the discharge was increased from 0.57 to 0.65 ℓ/min, 0.97 to 1.29 ℓ/ min and 7.12 to 9.53 ℓ/ min for 3.8, 5.2 and 13.6 *mm* bubbler tube diameters, respectively.

Table (3): The bubbler discharge and manufacturer's coefficient of variation of different effective head for bubbler tube diameters.

Mean effective pressure P_e, (*KPa*)	(Ø) *ID* 3.8 *mm*		(Ø) *ID* 5.2 *mm*		(Ø) *ID* 13.6 *mm*	
	Mean discharge (ℓ/min)	*Cv*	Mean discharge (ℓ/min)	*Cv*	Mean discharge (ℓ/min)	*Cv*
11	0.57	0.006	0.97	0.007	7.12	0.006
12	0.58	0.005	1.00	0.005	7.76	0.008
13	0.59	0.005	1.03	0.005	8.19	0.008
14	0.60	0.004	1.06	0.004	8.47	0.010
15	0.61	0.003	1.11	0.004	8.70	0.009
16	0.62	0.003	1.16	0.003	8.90	0.008
17	0.63	0.004	1.19	0.006	9.10	0.010
18	0.63	0.004	1.23	0.005	9.24	0.009
19	0.64	0.004	1.27	0.004	9.39	0.011
20	0.65	0.004	1.29	0.004	9.53	0.009

All correlation coefficients were above 0.95. Two bubblers diameters 5.2 and 13.6 *mm* were fully turbulent with bubbler discharge exponent 0.5 and 0.45 respectively. The third diameter 3.8 *mm* was partially pressure compensating with bubbler discharge exponent 0.23 according to their exponent *x* uses.

Bubbler manufacturer's coefficient of variation (*Cv*)

Cv values of the three bubbler diameters were ranged between 0.003 to 0.011 as shown in figure (3) at 11 to 20 *kPa* effective head respectively which considered excellent according to the classification of manufacturing variation coefficient for point source which recommended by ASAE Standards, (2000).

Discharge uniformity coefficient (*Cu*)

The outlet at equal elevation (first case)

Table (4) shows the Christiansen uniformity coefficient (*Cu*) for the three bubbler tubes diameter at equal elevation. It can be seen that the mean effective head (*he*) decreases due to increasing of bubbler height.

The bubbler discharge (*q*) was consequently decreases for all bubbler tube heights (h_b) from 0.0 to 1.0 *m* at three initial operating pressures for the three bubbler tube diameters. These results according to outlet elevation gradually rising up from the datum and variation on velocity head and pressure head.

Figure (2): The relationship between effective head and bubbler discharge for different bubbler tube diameters.

Figure (3): The relationship between effective head and manufacture coefficient of variation of different bubbler diameters.

Table (4): Bubbler mean effective pressure, discharge and uniformity at different initial pressure for internal bubbler diameters, at the same bubbler heights, (first case).

h_b m	ID, Ø mm	P_i kPa	mean effective pressure, P_e kPa	Mean discharge, q ℓ/min	Cu %	h_b m	ID, Ø mm	P_i kPa	mean effective pressure , P_e kPa	Mean discharge, q ℓ/min	Cu %
0	3.8	15	7.02	0.51	98.8	0.6	3.8	15	5.78	0.49	98.8
		30	24.38	0.68	98.8			30	22.06	0.67	98.8
		45	40.46	0.76	98.2			45	34.10	0.73	98
	5.2	15	12.96	1.03	94.4		5.2	15	11.44	0.97	94.6
		30	24.82	1.43	99.2			30	23.02	1.38	99.2
		45	35.58	1.72	96.8			45	33.06	1.66	96.8
	13.6	15	9.12	6.83	65.8		13.6	15	7.76	6.35	68.4
		30	15.72	8.70	56			30	14.06	8.30	58
		45	21.04	9.93	54.2			45	17.60	9.17	55.4
0.2	3.8	15	6.50	0.50	98.8	0.8	3.8	15	5.50	0.48	98.8
		30	23.40	0.68	98.8			30	21.30	0.66	98.8
		45	38.30	0.75	98			45	32.46	0.73	98.4
	5.2	15	12.12	1.00	94.4		5.2	15	11.02	0.95	94.8
		30	24.18	1.42	99.2			30	22.52	1.37	99.4
		45	34.66	1.70	96.8			45	32.20	1.64	96.8
	13.6	15	8.64	6.66	66.2		13.6	15	7.24	6.16	69.6
		30	15.00	8.53	56.8			30	13.68	8.17	58.6
		45	19.90	9.69	54.4			45	16.28	8.85	55.8
0.4	3.8	15	6.16	0.49	98.8	1.0	3.8	15	5.16	0.47	98.8
		30	22.76	0.67	98.8			30	20.74	0.66	98.8
		45	36.34	0.74	98.2			45	30.92	0.72	98.4
	5.2	15	11.84	0.99	94.6		5.2	15	10.56	0.94	95.6
		30	23.70	1.40	99.2			30	21.80	1.34	99.4
		45	33.86	1.68	96.8			45	31.18	1.61	97
	13.6	15	8.10	6.48	66.8		13.6	15	6.84	6.00	72.8
		30	14.4	8.39	57.6			30	13.08	8.02	62.2
		45	18.80	9.45	55.4			45	15.40	8.61	61.8

P_i : initial pressure P_e : effective pressure   Cu: Coefficient of uniformity

For all bubbler tube diameters (*ID*). At all bubbler tube heights (h_b) from 0 to 1.0 *m*., the discharge uniformity (*Cu*) were relatively constant for the same initial operating pressure (P_i) for *ID*, 3.8 *mm*. While for 5.2 *mm*, the uniformity coefficient (*Cu*) was increased with initial operating pressure increasing from 15 to 30 *kPa* and decreased with P_i increasing from 30 to 45 *kPa*. But for *ID*, 13.6 *mm*, the discharge uniformity coefficient was decreased with initial operating pressure increasing from 15 to 45 *kPa* as shown in figure (4). The highest values of discharge uniformity were recorded with *ID*, 5.2 and 3.8 *mm*, while *Cu* value was considered a marginal for *ID*, 13.6 *mm*. These results agree with Reynolds *et al*., (1995) which indicated that hose diameters greater than 10 *mm* are not recommended for low-head bubbler systems due to poor water distribution uniformity.

Figure (4): The relationship between bubbler height and coefficient of uniformity of bubbler diameters and different initial pressure, (first case).

Finally, the discharge uniformity was more sensitive to increase bubbler height with bubbler diameter 13.6 *mm* than 5.2 *mm*. Generally, the uniformity was increased with bubbler height increased from 0.4 to 1.0 *m*, as shown in figure (4.C). Also, there was inverse relationship between discharge and uniformity. As a result, the discharge uniformity increased with bubbler heights increasing, due to discharge decreased Figure (4). These results have a good agreement with Elmeseery, 1993.

The outlet parallel to the hydraulic gradient line (second case)

The relationship between bubbler tube diameters Ø, Initial operating pressure P_i, effective head *he*, bubbler discharge *q* and coefficient of uniformity *Cu*; displayed in table (5). It is clear that the discharge uniformity was very high in case of bubbler outlets which were parallel to the hydraulic gradient line compared to bubbler outlets which were at the same height. These results are in agreement with Rawlins, (1977), Behoteguy& Thornton, (1980), Hull, (1981) and Elmeseery, (1993).

Table (5): Bubbler hydraulic properties of different locations and internal bubbler diameters of the same effective pressure, (second case).

Ø ID mm	P_i kPa	h_e kPa	Mean discharge ℓ/min	Cu
3.8	15	6	0.50	99.8
		7	0.51	99.2
		8	0.52	98.6
	30	26	0.69	99.4
		27	0.70	99.2
		28	0.71	98.7
	45	38	0.74	99.2
		39	0.75	99.0
		40	0.76	98.5
5.2	15	10	0.91	99.2
		11	0.95	98.8
		12	1.00	98.6
	30	27	1.49	99.6
		28	1.52	99.3
		29	1.55	98.7
	45	30	1.58	99.1
		31	1.60	98.9
		32	1.63	98.6
13.6	15	7	6.06	95.4
		8	6.44	94.6
		9	6.79	92.8
	30	12	7.73	84.6
		13	8.00	82.8
		14	8.30	80.2
	45	22	10.20	62.4
		23	10.35	59.6
		24	10.56	56.3

Figure (5): The relationship between initial operating pressure and coefficient of uniformity at the same bubbler diameter, (second case).

Figure (6): Uniformity coefficient differences percentage, (second case).

As shown, the 13.6 *mm* bubbler tube diameter had the highest percentage of difference for uniformity compared to *ID* 3.8 and 5.2 *mm*, as shown in figure (6). This study is not recommended to use bubbler diameter *ID* 13.6 *mm* in low head bubbler irrigation systems.

For the bubbler tube diameters 3.8 and 5.2 *mm*, there were no significant changes in *Cu* between initial operating pressure from 15 to 45 *kPa* as shown in Figure (5 A, B). On the other hand, the discharge uniformity for 13.6 *mm* bubbler diameter was decreased with initial operating pressure increasing from 15 to 45 *kPa* as shown in figure (5 C). These results agree with Ngigi, (2008).

Conclusions

It has been concluded that the manufacture coefficient of variation *Cv* was laboratory calculated and its values ranged between 0.003 to 0.011 which considered excellent according to the classification of ASAE Standards, (2000). And the discharge uniformity was studied in two cases:

First Case: when bubbler outlet at the same level.

Second case: When bubbler outlet parallel to the hydraulic gradient line.

1. In first the case, It was inverse relationship between discharge and uniformity. The highest values of discharge uniformity (*Cu*) were recorded with *ID*, 5.2 and 3.8 *mm*, while (*Cu*) value was considered a marginal for *ID*, 13.6 *mm*
   - **a.** For *ID*, 3.8 *mm*, the discharge uniformity (*Cu*) with all bubbler tube heights from 0.0 to 1.0 *m* was relatively constant (98.8 to 98.4 %) with initial pressure from 15 to 45 *kPa*,
   - **b.** While for "*ID*" 5.2 *mm*, the uniformity coefficient (*Cu*) was slightly fluctuated from (94.4 to 97.0 %) with initial operating pressure (P_i) increasing from 15 to 45 *kPa*,

c. But for *ID*, 13.6 *mm*, the discharge uniformity coefficient (*Cu*) was decreased from (65.8 to 61.8 %) with initial operating pressure (P_i) increasing from 15 to 45 *kPa*.

2. In the second case when bubbler outlets were parallel to the hydraulic gradient line. It is proportionally same bubbler discharges along the lateral pipe.

It is clear that the discharge uniformity in the second case was higher than the first case, but there were no significant changes in (*Cu*) with *ID* 3.8 and 5.2 *mm* with initial operating pressure increasing from 15 to 45 *kPa* compared with the *ID* 13.6 *mm* bubbler tube diameter.

3. Due to no significant difference in *Cu* values between two cases of low head bubbler design, it was recommended that use simple design in the first case than the second case with bubbler diameter 3.8 and 5.2 *mm* in compared with 13.6 *mm* bubbler tube diameter

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تقييم أداء نظام ري فوار ذو ضاغط منخفض

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الهدف الأساسي لهذا البحث تقييم أداء ثلاث أقطار للنافورات تحت ثلاث ضغوط تشغيل ابتدائية ١٥، ٣٠، ٤٥ ك باسكال لتحديد الحالة المثلي التي تحقق اعلي انتظامية. حيث تم إنشاء وحدة اختبار تجريبية بمزرعة كلية الزراعة جامعة قناة السويس بالإسماعيلية. وتم دراسة انتظامية توزيع المياه في حالتين:
أولا: مخرج النافورات في نفس المستوي عند ارتفاع النافورات ٠٠. ، ٠.٢، ٠.٤، ٠.٦، ٠.٨و ١.٠م.
وأظهرت النتائج أن أعلى قيم لمعامل انتظامية التوزيع *Cu* تم الحصول عليها لقطر نافورة ٥.٢ مم مع ضغط تشغيل ٣٠ ك باسكال حيث كانت قيم الانتظامية تقريبا ثابتة بمتوسط ٩٩.٣ %.
ثانيا:مخرج النافورات موازي لخط الميل الهيدروليكي وذلك تحت تأثير ثلاث ضغوط فعالة لكل ضغط تشغيل ابتدائي حيث كان واضحا انه يعطي نفس التصرف من جميع النافورات للقطر ٣.٨ و ٥.٢ مم ولكنه يعطي تصرفات مختلفة مع القطر ١٣.٦ مم.
و يوصى بتشغيل قطر نافورة ٥.٢ مم مع ضغط تشغيل ابتدائي ٣٠ ك باسكال لتحقيق معامل انتظاميه عاليه بالإضافة لتحقيق خط جانبي أطول مقارنة عند استخدام نافورة بقطر٣.٨ مم لتقليل تكلفة إنشاء النظام الأولية. أوضحت الدراسة أن قطر نافورة ١٣.٦ مم غير موصي بها لنظام الري الفوار ذو الضاغط المنخفض نتيجة لقلة انتظامية توزيع المياه.

قام بتحكيم البحث

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