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**Suez Canal University
Faculty of Agriculture
Agricultural Engineering Department**



STUDIES ON LOW-HEAD BUBBLER IRRIGATION SYSTEM DESIGN

By

AHMED ABDEL-KAREEM HASHEM ABDEL-NABY
B. Sc., Agric. Mechanization, Suez Canal University, 2006

**Thesis
Submitted in Partial Fulfillment of
the Requirements for the Degree of
Master of Science**

In

**Agricultural Sciences
(Agricultural Engineering)**

**Agricultural Engineering Department
Faculty of Agriculture
Suez Canal University**

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Agricultural Engineering Department
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2011

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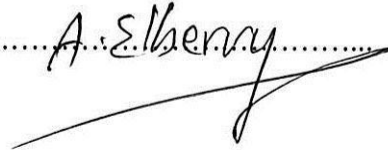
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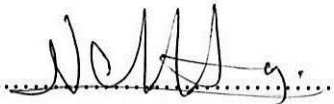
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ABSTRACT

The aim of this research was to investigate the performance of three bubbler tube diameters of 3.8, 5.2 and 13.6 *mm* at three initial operating pressure of 15, 30, 45 *kPa* to determine optimum operating conditions that achieve high discharge uniformity. The experimental work was conducted at the farm of agricultural faculty, Suez Canal University, Ismailia. The coefficient of uniformity (*C_u*) 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 operating pressure of 30 *kPa* and bubbler diameter 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 pressures for each initial operating pressure. The results show that all bubbler tubes were along the lateral line give the same discharge for 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* with 30 *kPa* initial operating pressure for 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.

Key words:	Bubbler irrigation, Low Head Irrigation, Coefficient of Uniformity (<i>C_u</i>), Bubbler Irrigation Performance.
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1. INTRODUCTION

The water resources in Egypt are becoming scarce which a ninety percent of water is supplied by Nile. Egypt has 55.5 billion cubic meters according to the 1959 arrangement with Sudan and there are other parties trying to reduce Egypt's share of Nile water. With a population of approximately 76 million in 2009 and expected to increase to some 86 million by 2025, water consumption is about 730 m³ per year (2009) to about 639 m³ per year (2025) which is considered below the water poverty level (1,000 m³/year/capita).

The efficient use of water in Egypt has now become a strategic goal. By law, new reclaimed lands have to be irrigated with pressurized irrigation systems. Pressurized irrigation systems, in the form of sprinklers and microirrigation, have played an important role in improving irrigation efficiency and water application uniformity during the past several decades.

Microirrigation is the technique that uses closed-conduit pipes to apply irrigation water to the soil near the plant root zone. The advantages of microirrigation are numerous. Water and energy savings are the most important advantages which it is a smaller in usage water and energy than other modern irrigation systems.

Microirrigation systems can be broadly categorized into four types; drip, spray, bubbler and subsurface systems, based on their difference in hydraulic design or the method used to apply water to the soil. Microirrigation achieves higher irrigation efficiency and higher yields than other irrigation systems, but with the expense of high energy

consumption, capital cost and maintenance requirements to keep mechanized pumps and filtration systems operational.

The name of the bubbler system is derived from the fountain of water streaming out from the hoses, and from the bubbling noise made as air escapes from the pipe line when the system is turned on (**Reynolds *et al.*, 1995**).

In bubbler irrigation, water is applied to the soil surface as a little stream. bubbler systems can be further sub-divided into high and low pressure systems, low head bubbler systems are based on gravity-flow (about 10 *kPa*) from a small diameter tube (1 *mm* to 13 *mm*) and pressurized systems (50 to 150 *kPa*). Bubbler system are restricted to slope of 1-3%, and do not require mechanical pumps or filtration systems. So that the low head bubbler irrigation is considered one of the resolving problem of water scarcity and saving energy in Egypt.

Therefore, the objectives of this study were to:

1. Study the effect of different pressures and bubbler diameters on discharge uniformity
 - When the bubbler outlets at equal elevation.
 - When the bubbler outlets parallel to the hydraulic gradient line.
2. Determine the optimum height of each bubbler diameter to achieve high discharge uniformity.
 - When the bubbler outlets parallel to the hydraulic gradient line.

2. REVIEW OF LITERATURE

2.1. Bubbler Definition and Application

Reynolds (1993) Mentioned that the microirrigation system subdivided into four categories related to their difference in hydraulic design: drip, spray, bubbler, and subsurface systems. The design of bubbler system differs from design of other microirrigation systems because they are based on gravity flow and do not required external energy or elaborate filtration systems. The fact that the dissemination of bubbler design has occurred largely by site visits to existing bubbler systems probably indicates that available literature does not adequately described the simplicity of bubbler design.

Carr and kay (1980), James (1988) and Lamm *et al.* (2007) described that 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 to save water near the plant root zone. Two major types of bubbler irrigation systems are available high and low pressurized systems. The low head bubbler systems are based on gravity flow (about 10 to 50 *kPa*) and pressurized systems (50 to 150 *kPa*). **Hull (1981)** stated that bubbler system is restricted to slope of (1-3%). **Rawlins (1977), Behoteguy and Thornton (1980), Carr and Kay (1980) and Hull (1981)** define low head bubbler irrigation system that reduces the energy requirement. This is a type of microirrigation system that typically delivers flow rates of (0.032 to 0.063 ℓ /sec) to each tree through a small diameter polyethylene (*PE*) tubing (delivery hose) attached to a large diameter lateral of corrugated

plastic pipe which is buried between two tree rows by using (38.1 to 120 mm) diameter of (PE) lateral pipe.

Awady *et al.* (1975) developed the first trickle irrigation system installed and tested in Egypt as early as 1973. The system was operated on a very low head of 40 cm, being close to bubbler it proved to reduce clogging problem.

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. 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.

Hull (1981) illustrated that the bubbler irrigation is very sensitive to changes of pressure head, and a constant head source is essential for a commercial orchard or plantation. A change in pressure head at the inlet to the system results in non-uniformity of application at each outlet. A pressure head of one meter is very small, and small changes in head can thus have a marked effect on the flow rate, which is fixed once the system is installed and is not easily changed.

Bubbler systems are well suited for perennial crops, particularly orchards and vines, because the irrigation system typically includes buried pipes and small earthen basins around the plantings. Bubbler systems can also be adapted to row crops that utilize furrows. The laterals

are placed along the furrows after planting and are removed from the field following harvest. A fine soil texture is also preferred. Bubbler systems can readily utilize low-head water supplies, similar to surface irrigation systems. The following sections outline advantages and disadvantages of bubbler systems relative to other types of microirrigation systems **Lamm *et al.* (2007)**.

2.2. Advantages and Disadvantages of Bubbler Irrigation

Behoteguy and Thornton (1980), Hull (1981), phocaides (2000) and Lamm *et al.* (2007) indicated that bubbler systems have some advantages and disadvantage compared with other microirrigation systems.

Advantages	Disadvantages
Energy requirements are low due to apply water by gravity flow.	Very few agricultural bubbler systems have been installed.
Maintenance is low as a result of useless equipment (filters, pumps).	Design criteria and recommended operating procedures are not well documented.
Susceptibility to emitter clogging is low due to large diameter delivery hose.	Entrapment of air in the pipe network can lead to blockages.
Water with higher suspended solids concentration can be used.	Farm topography needs to be nearly level.
Operating costs are low because of the lower energy and maintenance requirements.	Bubblers are not suitable for sandy soils due to its large infiltration rate.
Intervals between irrigations are long.	Small earthen basins are typically required around plants to hold the water near the root zone.
Duration of an irrigation event is short because the large discharge rates.	Cultural practices are more difficult to perform around earthen basins.
Accumulated salts are uniformly leached.	Small water flow cannot be used as in other microirrigation systems.

Bubbler basins increase catchment's of rainfall.	Limited to orchard and plantation type crops because of costs.
High irrigation application uniformity up to 75 percent.	Possibly more leaching and evaporation losses than with trickle irrigation system.
The entire piping network is buried therefore no problems in field operations.	Usually greater water consumption than trickle system.
The technology is simple and no highly sophisticated equipment is used.	The bubbler concept has not been widely adopted in agriculture
The initial cost and maintenance costs are low comparable with other microirrigation systems.	
Reduced tail water.	
The ability to more precisely apply nutrients to the tree.	
The system can be operated by unskilled farmers and laborers.	

2.3. Design of Bubbler Irrigation System

Design procedures for gravity systems have been developed over the last several years and are relatively unique to this type of irrigation.

Rawlins (1977) reported that to ensure equal discharge from all delivery hoses, the elevation of each delivery hose was calculated by subtracting from the static head, the friction losses in the pipes and the change in elevation. After the delivery hoses were installed at these computed elevations, the outflows of the delivery hoses were adjusted to be approximately equal by dynamically calibrating the system.

Dynamic calibration is a procedure by which errors in friction loss calculations can be evenly distributed along the lateral by adjusting the elevation of each delivery hose. Dynamic calibration is performed after

the delivery hose elevations have been set at their calculated elevations. The discharge uniformity values of 89.2% before dynamic calibration at Tacna, Arizona and 97.3% uniformity at Riverside after dynamic calibration.

Designing a bubbler irrigation system includes designing the lateral line, delivery tube and determining the bubbler outlet level (bubbler height) **Behoteguy and Thornton (1980)**.

2.3.1. Delivery tube design

Emitters for gravity flow bubblers are unique in that they are not designed to dissipate energy, unlike those associated with the other types of microirrigation. Bubbler emitters are essentially delivery tubes for transferring water from irrigation laterals to the plants.

The delivery hose length was calculated by using the following equation according to (**Lamm *et al.*, 2007**)

$$L_{dh} = 0.5 S_r + d_l + H_{max} \quad (2.1)$$

Where:

L_{dh} : Delivery hose length, m

S_r : Plant spacing, m

d_l : Depth of lateral burial, m

H_{max} : Maximum delivery hose height, m .

Small changes in elevations throughout the system have a large impact on discharge rates. Additionally, friction losses within the pipes and tubes affect water pressures within the system, and therefore affect discharge rates. Although discharges are usually less than (225 ℓ/h),

friction losses in the delivery tubes do affect the flow rates. These losses must be estimated and handled through proper selection of tube diameter. For small diameter, smooth pipes, the Darcy-Weisbach and Blasius equations can be combined to predict friction head loss, $h_f(m)$, accurately in bubbler tubes (**Keller and Bliesner, 1990**):

$$h_f = K_{fdw} \frac{Q^{1.75}}{D^{4.75}} L \quad (2.2)$$

Where:

h_f : Friction head losses, m

D : Inside diameter, mm

Q : Flow within tube, ℓ/s

L : Length of tube, m and

K_{fdw} : a constant = 7.89×10^5 for SI units at a water temperature of $20^\circ C$.

The head loss gradient (pipe friction loss as a function of length) for a variety of pipe diameters and flows are given in Figure (2.1). Generally, bubbler laterals are centrally situated between plant rows with delivery tubes placed on both sides of the lateral. Tube lengths can range from less than $1 m$ in row crops to more than $5 m$ for orchards.

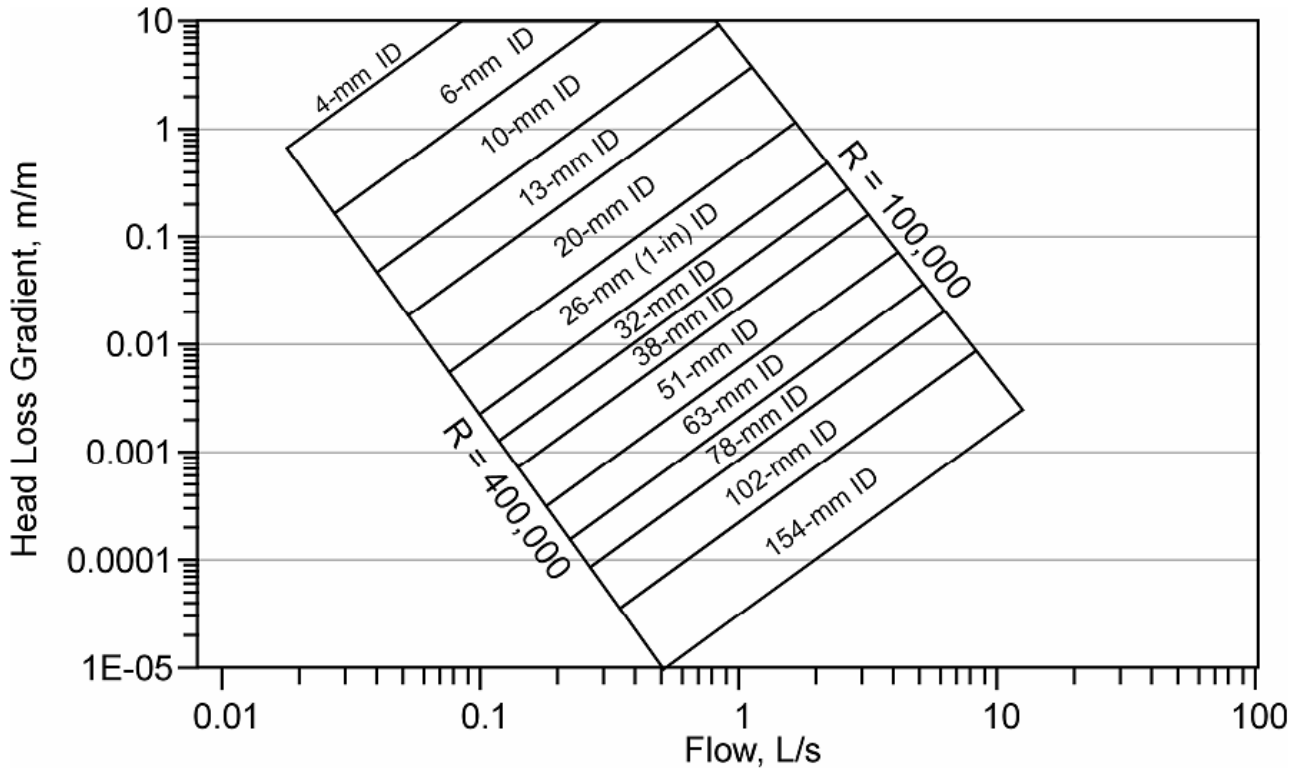


Figure (2.1): Head loss gradient for smooth (*PE* and *PVC*) pipe for Reynold's Numbers (*R*) between 100,000 and 400,000 and for a water temperature of 20°C. **Reynolds et al. (1995)**.

Discharge rate as a function of tube length can be derived from fundamental hydraulic principles. Energy conservation within the bubbler tube can be described by the Bernoulli's equation as:

$$\frac{p_1}{\gamma} + Z_1 + \frac{V_1^2}{2g} = \frac{p_2}{\gamma} + Z_2 + \frac{V_2^2}{2g} + \sum hf + \sum h_{ml} \quad (2.3)$$

Where:

hf: Friction head loss in pipes, *m*

h_{ml}: Minor loss at pipe fittings, *m*

V₁ and *V₂*: Flow velocities of water in the pipe at locations 1 and 2, respectively, *m/s*

P_1 and P_2 : Pressures within the pipe at locations 1 and 2, respectively, kPa

Z_1 and Z_2 : Elevations of pipe at locations 1 and 2, with respect to a reference datum, m

γ : Specific weight of water, $9790 N/m^3$ at $20^\circ C$ and

g : Gravitational constant, $9.81 m/s^2$.

When applying equation (2.3) to a bubbler tube, points 1 and 2 can be set at the entry and outlet of the tube. Several assumptions can then be made to simplify the equation, as follows:

- 1- Minor losses (h_{ml}) are zero;
- 2- No elevation change along tube, $Z_1 = Z_2$;
- 3- Continuity equation applies, $V_1 = V_2$ and
- 4- $P_2 = 0$, atmospheric pressure.

Based on the preceding assumptions and by defining the head loss, h_f , by equation (2.2), the following equation defines the bubbler tube discharge:

$$q_b = K_b \left(\frac{P}{L_b} \right)^{0.57} D^{2.71} \quad (2.4)$$

Where:

q_b : Bubbler tube discharge, ℓ/h

p : Operating pressure, kPa

L_b : Length of bubbler tube, cm

D : Diameter of bubbler tube, mm and

K_b : a constant= 5.52 for units of variables as defined.

equation (2.4) can then be rearranged to solve for L_b , giving

$$L_b = K_1 \left(\frac{D^{4.75}}{q_b^{1.75}} \right) P \quad (2.5)$$

Where:

$K_1=19.88$ is a constant for the variables as defined in equation (2.5), **Lamm *et al.* (2007)**.

If the delivery tubes are cut to the same length, the flow to the tree basin will be controlled only by the height of the delivery tube outlet. Every hose could be attached conveniently to each tree by stapling the delivery tube from the lateral to the trunk of the tree and installing a barbed tee with its horizontal side arm at the desired out flow elevation as shown in Figure (2.2), **Rawlins (1977)**.

El-meseery (1993) explains that the principal equations of pressurized irrigation systems were used to derivate an equation for bubbler irrigation system design. When the delivery's outlets were parallel to the hydraulic gradient line, the discharge uniformity coefficient (Cu) was about (99) percent, but when the delivery's outlets were at the same level, the discharge uniformity coefficient (Cu) increased with decreasing of the initial operating pressure.

2.3.2. Delivery tube elevation (bubbler height)

Studied uniform irrigation with a low head bubbler system. **Rawlins (1977)** described two procedure used to determine the proper elevation of the supply hose at each tree to provide equal flow rate. First, by standing water at a fixed static head in the lateral, a reference level was found and marked on each tree by lowering each supply hose until the water level stands at its opening.

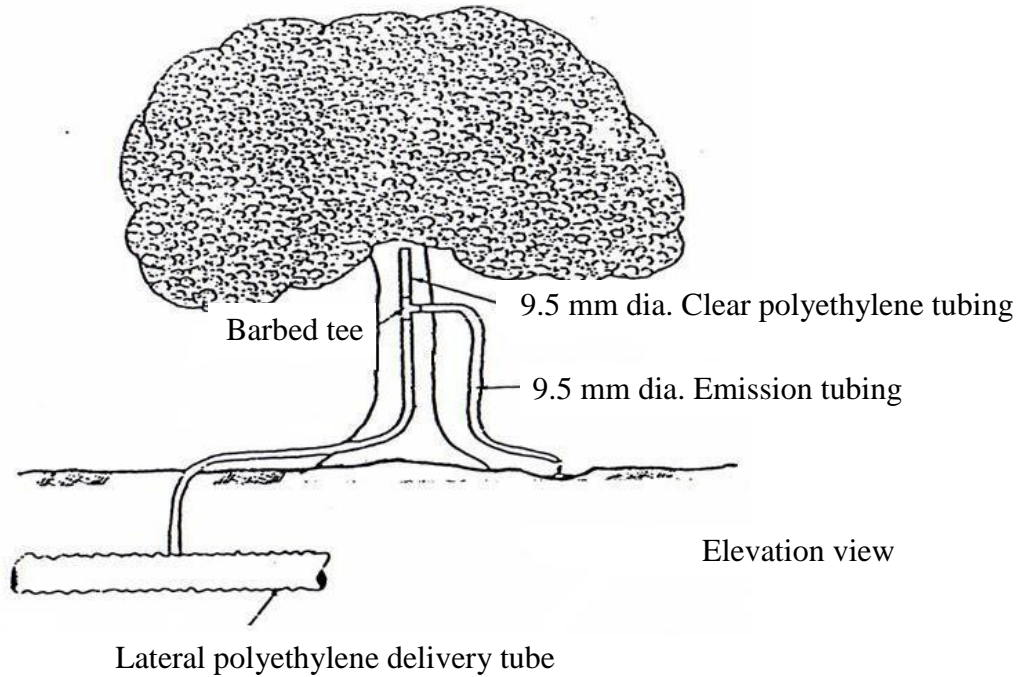


Figure (2.2): Typical installation of bubbler irrigation system (**Behoteguy and Thornton, 1980**).

During the procedure, all other hoses were kept elevated above this level so that water did not flow them, causing a pressure head gradient within the lateral. All subsequent elevation measurements were made relative to this reference elevation. Second estimating the head losses that would occur with the lateral between each pair of connections when the system was operated. This head loss in the lateral was then compensated by lowering the point of attachment of the supply hose from one tree to another by a distance equal to it. Hydraulic head, delivery hose outlet, and ground levels as a function of distance from the water source are shown in Figure (2.4).

Rawlins (1977) added that because the bubbler irrigation system operates at low pressure, the existing elevation of pipes used for furrow or flood irrigation should often be sufficient to provide it. There is, of course, a minimum elevation required, either to keep the lateral pipe size

within economic limits, or in some cases to maintain flow velocities high enough either to prevent siltation or to allow periodic flushing.

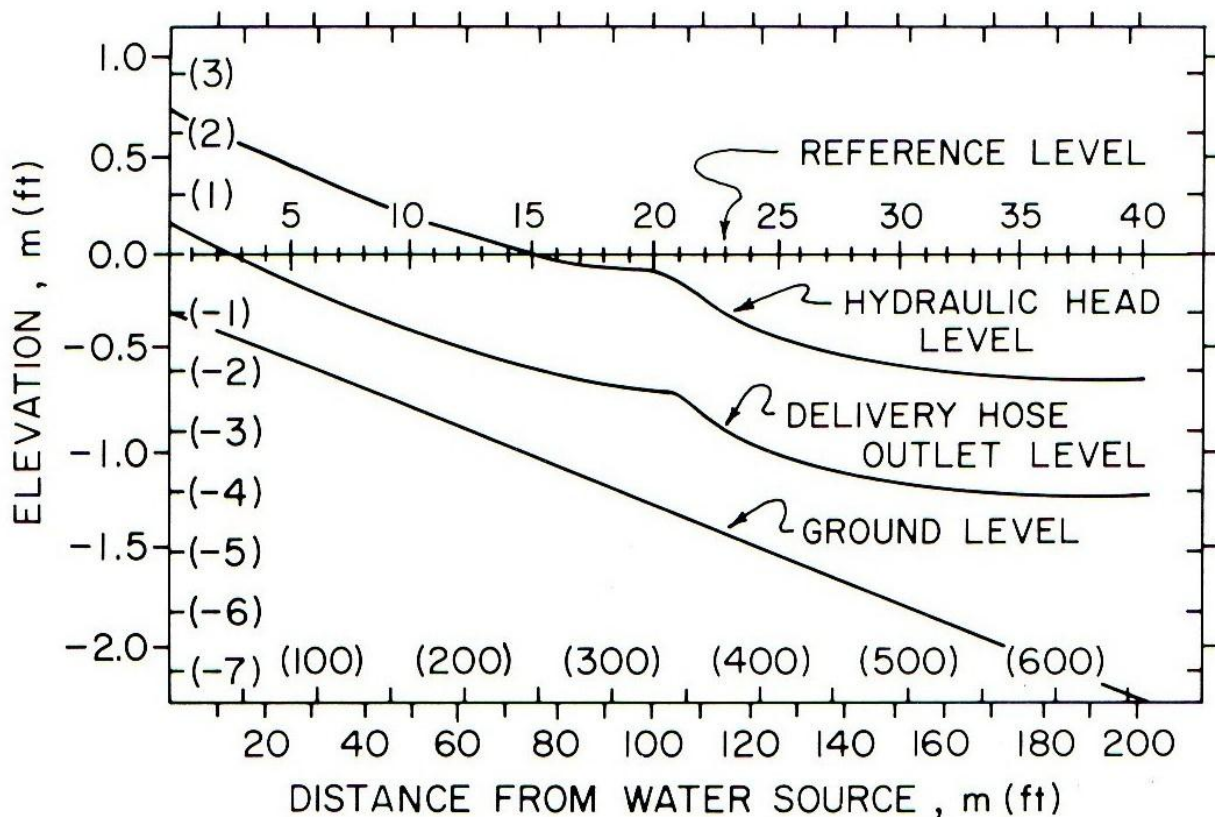


Figure (2.3): Hydraulic head, delivery hoses outlet and ground levels as a function of distance from the water source. The lateral pipe *ID* changes from 102 *mm* (4 inches) to 76 *mm* (3 inches) at 100 *m* (330 *ft*) (**Rawlins, 1977**).

Hull (1981) gave the following procedure for adjusting of bubbler level:

1. Find the reference level by raising all delivery hoses until no flow occurs in the system and water stand at the delivery hose exists.
2. Calculate the total head losses in the lateral to each tree, making sure that this does not exceed the total head available at any tree.

If it does, then larger pipe size will have to be used to reduce head losses. Measure a distance downwards from the reference level at each tree

3. With the system operating, at each delivery hose in turn, rise the delivery hose until downwards from the reference level. This refines the system and allows for any discrepancies in lateral head from reference level.
4. Measured the discharge at each tree to confirm the discharge expected.

Generally, all delivery hoses in a system are assumed to have the same length and the maximum and minimum delivery hose heights are assumed to equal 1.0 m and 0.3 m (3.3 ft and 1 ft), respectively. Delivery hoses set at elevations lower than 0.3 m (1 ft), risk damage from ponded water or trampling by workers or animals. Delivery hose heights could be set at heights higher than 1 m (3.3 ft), but the falling water would increase soil erosion at the point of impact. One way to increase delivery hoses heights without increasing soil erosion is to place a tee at the point of discharge of the hose, and run a delivery tube from the side of the tree down to the basin **Reynolds et al. (1995)**.

Abozaid et al. (1998) derived an equation to determine the bubbler height achieving high uniformity of discharge.

The driven equation is expressed mathematically as follows:

$$hbn = H_i - h_e - h_{ln} \quad (2.6)$$

$$hbn = H_i - \left(\frac{q}{a}\right)^{\left(\frac{1}{b}\right)} - \left[\left(61111 \times q^{1.75} \times D^{-4.75} (s + cl) \sum_{n=1}^N (N - n + 1)^{1.75} \right) \right] \quad (2.7)$$

Where:

h_{bn} : Bubbler height at "n" number, *cm*

H_i : Initial head, *cm*

h_e : Effective head, *cm* and

h_{in} : Total head losses at bubbler location, *cm*.

q : Bubbler discharge, ℓ/min

D : Lateral line inside diameter, *mm*

S : Distance between bubblers, *m* and

N : Total number of bubblers.

2.3.3. Lateral line and manifold design of bubbler irrigation

Lamm *et al.* (2007) explained that Laterals and manifolds for bubbler systems are typically constructed from smooth *PVC* and/or corrugated *PE* pipe. Due to the relatively high emission discharge rates, the diameters of laterals and manifolds are generally larger and/or their lengths are shorter than those in other microirrigation systems. For typically sized lateral and manifold *PVC* pipes used in bubbler systems, the Hazen-Williams equation is used for predicting friction head loss, h_f (*m*), as a function of flow rate, pipe length, and pipe diameter. The following Hazen-Williams equation is very similar to the Darcy-Weisbach derived equation (2.2) used for small diameter bubbler tubes:

$$h_f = K_{fhw} \frac{Q^{1.85}}{D^{4.87}} L \quad (2.8)$$

Where:

h_f : Friction head loss, *m*

K_{fdw} : = 1.135×10^6 , a constant for SI units at 20°C ,

Q : Inlet flow rate, ℓ/s

D : Inside pipe diameter, *mm* and

L : Length of pipe, *m*.

The Christiansen reduction coefficient, F , can be applied to equation (2.8) to account for head loss in pipes that their discharge flow uniformly along the pipe's length via laterals and manifolds. Reduction coefficients are listed in Table (2.1). Depending on the location of the first outlet relative to the lateral's inlet, F_1 , F_2 , or F_3 is selected. F_1 is used when the distance from the lateral inlet to the first outlet is Sb . F_2 is used when the first outlet is adjacent to the lateral inlet. F_3 is used when the distance from the lateral inlet to the first outlet is $Sb/2$. With minor modification to equation (2.8), taking into account the outlets for the bubbler tubes, the following equation gives the total head loss for a lateral or manifold, with the same notation as described earlier:

$$h_f = K_{fhw} \frac{Q^{1.85}}{D^{4.87}} L \quad (2.9)$$

Because of its relatively low cost, corrugated *PE* pipe can also replace *PVC* pipe for low-pressure systems. Friction head loss, however, is greater for the corrugated *PE*, and the values presented in Figure (2.1), which were established for smooth pipes, are not applicable. According to **Hermsmeier and Willardson (1970)** the friction head loss equation for corrugated plastic pipe for a water temperature of 20°C is

$$h_f = K_p \frac{Q^2}{D^5} L \quad (2.10)$$

Where:

h_f : Friction head loss, *m*

Q : Inlet flow rate, *ℓ/s*

D : Inside pipe diameter, *mm*

L : Length of pipe, *m* and

K_p : a constant= 5.78×10^6 for units of variables as defined.

The friction loss gradient for corrugated plastic pipe, (h_f/l), as calculated in equation (2.10), is presented in Figure (2.4) for pipe diameters between (51 and 204 *mm*) and flow rates between (0.2 and 100 ℓ/s). Laterals and manifolds are sized according to the allowable friction loss in the system, by taking into account the reduction coefficient, F , as described in equation (2.8) and Table (2.1).

Selection of pipe size for the manifold is to a large extent an economic decision, which involves balancing friction losses against various economic factors. One common method of pipe size selection is the “percent head loss method,” where the allowable friction loss in the manifold is limited to (5 to 20%) of the irrigation system’s design head, (H_d), (**Keller and Bliesner, 1990**). In practice, both the (5 and 20%) conditions are often calculated, and the final decision is based on the calculated results and on additional factors such as price differences, availability, installation, maintenance requirements, and end-user preferences.

Table (2.1): Coefficients of F for plastic pipe **Benami and Ofen (1984)**.

Number of outlets	F_1 ^[1]	F_2 ^[2]	F_3 ^[3]
5	0.469	0.337	0.410
10	0.415	0.350	0.384
12	0.406	0.352	0.381
15	0.398	0.355	0.377
20	0.389	0.357	0.373
25	0.384	0.358	0.371
30	0.381	0.359	0.370
40	0.376	0.360	0.368
50	0.374	0.361	0.367
100	0.369	0.362	0.366

^[1] F_1 is used when the distance from the lateral inlet to the first outlet is S_b .

^[2] F_2 is used when the first outlet is adjacent to the lateral inlet.

^[3] F_3 is used when the distance from the lateral inlet to the first outlet is $S_b/2$.

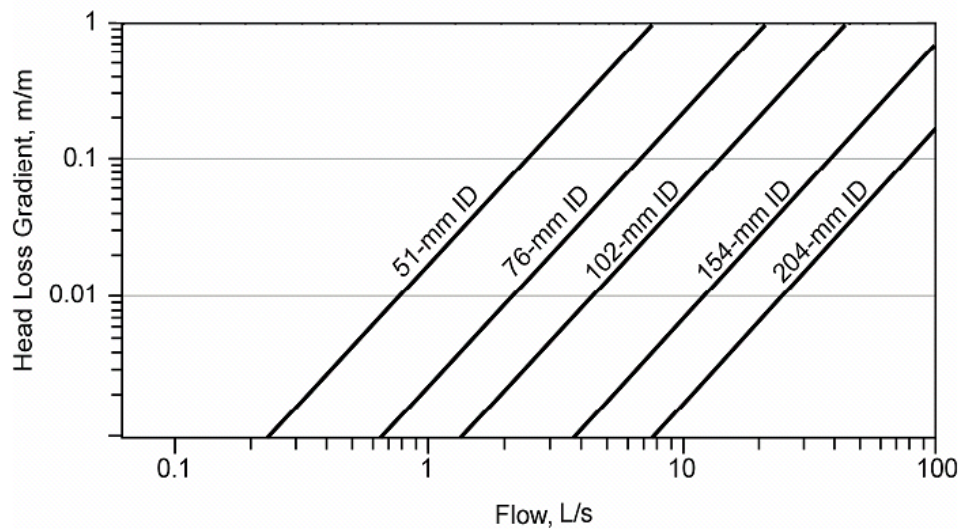


Figure (2.4): Head loss gradient for corrugated *PE* pipe, water temperature at 20°C **Reynolds et al. (1995)**.

The allowable friction loss in the manifold, (h_{fam}), may then be expressed by the following equation for either (5% or 20%) of the irrigation system's design head:

$$h_{fam} = \frac{\left(5\% \text{ or } 20\%\right)}{100} \times H_d \quad (2.11)$$

The allowable head losses gradient in the manifold is then expressed as

$$h_f / L = h_{fam} / (F \cdot L_m) \quad (2.12)$$

Where:

h_{fam} : Allowable friction loss in the manifold, m

H_d : Design head, m

L_m : Length of the manifold, m and

h_f/L : Allowable head losses gradient in the manifold.

In addition to friction loss in pipes, the slope of the field is a variable to consider in designing laterals and manifolds. Elevation differences are especially critical to gravity systems because minor changes in elevation head may have a significant effect on pressures within the system. Additional considerations for bubbler systems include equipment in the control head and air release hardware in gravity flow networks. Clogging of bubbler tubes in low-pressure systems is usually not a concern because tube openings are relatively large. Injection hardware for fertilizers and other chemicals may also be incorporated in bubbler systems.

For gravity bubbler systems, a constant head device is required when the water source (reservoir or canal) is not maintained at a constant

elevation. A constant head device (e.g., standpipe and gate valve) can be installed near the water source or elsewhere along the mainline to maintain a constant design head during bubbler operation.

2.3.4. Minor losses

Keller and Karmeli (1975) and James (1988) substituted the head losses due to the emitter connection by an equivalent length added to the length of lateral line. The typical equivalent length for various emitter connections (fitting) to the lateral line as follows:

1. In line with barbed or layout connection from (1.0 to 3.0 *m*),
2. On-line with barbed connections from (0.1 to 0.6 *m*),
3. In-line with smooth connection which does not appreciably restrict the flow from (0.3 to 1.0 *m*).

Watters and Keller (1978) presented that the barbed friction losses (*cl*) in terms of a length of lateral that produces a friction loss of the same magnitude of the localized loss produced by the barb. They presented graphic data on emitter barb losses for various pipe diameter and barb dimensions. The following equation (with a correlation coefficient of $R=0.99$) was based on their results.

$$Cl = 0.25 W(19 D^{-1.9}) \quad (2.13)$$

Where:

Cl : Equivalent length of pipe, *m*

W : Emitter barb diameter, *mm* and

D : Diameter of lateral *mm*.

2.3.5. Air-locks elimination

Air locks are often found in low-pressure gravity-flow systems where pockets of air may accumulate at the crest of pipe undulations. These air pockets absorb a significant amount of energy and may partially block the flow of water. When the flow is entirely blocked by air, no water will be discharged until the air is removed.

Installation of relief valves or standpipes just downstream from the crest of pipe undulations is the most common method to release air accumulations in water lines. However, installing air valves in bubbler systems is not a practical or economical solution. Although air relief valves may be installed throughout the system, a more cost effective procedure is to maintain pipe velocities greater than 0.3 *m/s*. At these velocities, water turbulence prevents air accumulation in the pipes. Therefore, emission tubes less than (13 *mm*) in diameter are recommended for these hydraulic conditions to be achieved under low-pressure operation. From empirical data, the following equation can be used to calculate the minimum pipe flow rate to prevent air locks in both types of bubbler systems:

$$Q = K_a D^{2.45} \quad (2.14)$$

Where:

Q: Flow within pipeline, *ℓ/s*

D: Inside diameter of the pipeline, *mm*

K_a: is equal to 0.0001, a constant for units of variables as defined (**Reynolds and Yitayew, 1995**).

Jordan (1984) gives a good analysis of air locks and how to avoid them in the design of gravity-flow water supply systems, but his analysis

is not directly applicable to bubbler systems science his analysis is for water supply system with large elevation differences and long lengths of pipes. To prevent air locks from occurring in small-diameter pipes.

Harrington (1971) suggests the following:

Avoid air locks by:

- Eliminating pipe undulations,
- Keeping the hydraulic gradient line above the pipeline.
- Ensuring air does not enter at the pipeline inlet.
- Ensuring that pipe flow will be sufficient to flush out air in the pipeline under the water condition.

Relive air locks by

- Providing outlets, air valves or standpipes, at critical locations along the pipeline.
- Arranging the water supply so that higher pressure can be introduced at the start of operation, and then cut back to normal pressure after all air has been flushed from the line.

Waheed (1990) revealed that the undulations which are created during field installation are the primary cause of air locking. The head needed to flush out the trapped air is independent of tubing diameter, shape of the undulations and presence of water in the lower portions of undulations, but depends on the sum of heights of successive undulations. It was concluded that if the sum of heights of all the undulations exceeds the maximum allowable head losses in the tubing, water will not be able to flow out of the tubing.

2.4. Hydraulic Evaluation of Bubbler Irrigation System

The hydraulic performance used to determine the characteristics of the bubbler systems and also to verify and compare the published data of many researchers and manufacturers. Hydraulic evaluation 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.

2.4.1. Bubbler discharge

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

$$q = k h^x \quad (2.15)$$

Where:

q : 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.

The lower x value, the less discharge will be affected by variations in pressure. The sensitivity to h of a bubbler discharge depends mainly on the value of x , which determines how sensitive the discharge is to pressure. The value of x typically falls between, (0.1 and 1.0) mainly pending on the make and design of the bubbler, i.e. hydraulic characteristics.

Table (2.2): Recommended classification of flow regime according to the value of x as follow.

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 & Hiler, 1972; Wu & Gitlin, 1973; Howell & Hiler, 1974; Karmeli, 1977; Solomon & Bezdek, 1980; Braud & Soon, 1981 and Boswell, 1985)

The flow from non-compensating orifices and nozzle bubblers are always fully turbulent with $x = 0.5$. However, the exponent of long path bubblers may range anywhere between 0.5 for fully turbulent flow and $x = 1$ for laminar flow (Karmeli, 1977).

2.4.2. Coefficient of manufacturing variation C_v .

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.

ASABE Standards (2006) classified emitters based on coefficient of manufacturer's variation (C_v). Table (2.3) illustrates the recommended classification of (C_v) for point source emitter as indicated:

Table (2.3): Recommended classification of manufacturer's coefficient of variation (C_v), according to **ASABE Standards (2006)**.

C_v 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

Wu et al. (1985) reported that the total emitter flow variation is mainly affected by manufacturer's variation, temperature changes, and bulging. Assuming the temperature variation is small and the plugging problem is under control, the total emitter flow variation will be referring to the variation caused by the manufacturer.

Wu et al. (1979) showed that hydraulic design of drip irrigation lateral line is usually based on a design criterion using an emitter flow variation (q_{var}) of either (10 or 20%) which is equivalent to coefficient of variation (s/q) of (3 or 6%) where (s) is the standard deviation of emitter flow and (q) is the mean emitter flow.

Bralts (1978) and Solomon (1979) indicate that the manufacturer's variation is more significantly attributing to the total flow variation than the variation caused by hydraulics. If the design is made according to (10 or 20%) emitter flow variation hydraulically.

2.4.3. Coefficient of discharge uniformity Cu .

The uniformity coefficient (Cu) was calculating by (**Perold, 1977**) equation bubbler irrigation system as follows:

$$Cu (\%) = (1 - |\bar{\sigma}|) \times 100 \quad (2.16)$$

Where:

Cu : Coefficient of uniformity, % and

$|\bar{\sigma}|$: Absolute mean deviation of discharge on lateral line.

The $|\bar{\sigma}|$ was calculated by using the formula:

$$\bar{\sigma} = \frac{\sum (q - \bar{q})}{n} \quad (2.17)$$

Where:

n : Number of bubblers

\bar{q} : Discharge mean equal to $\frac{\sum q}{n}$, ℓ/s and

q : Discharge from bubbler, ℓ/s .

The (Cu) is a better way of expressing the variation discharge on 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 tube height along lateral line, this study was carried out to get an appropriate system for bubbler irrigation by changing of outlets diameters along lateral line.

Awady and Habib (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 as shown in Figure (2.5).

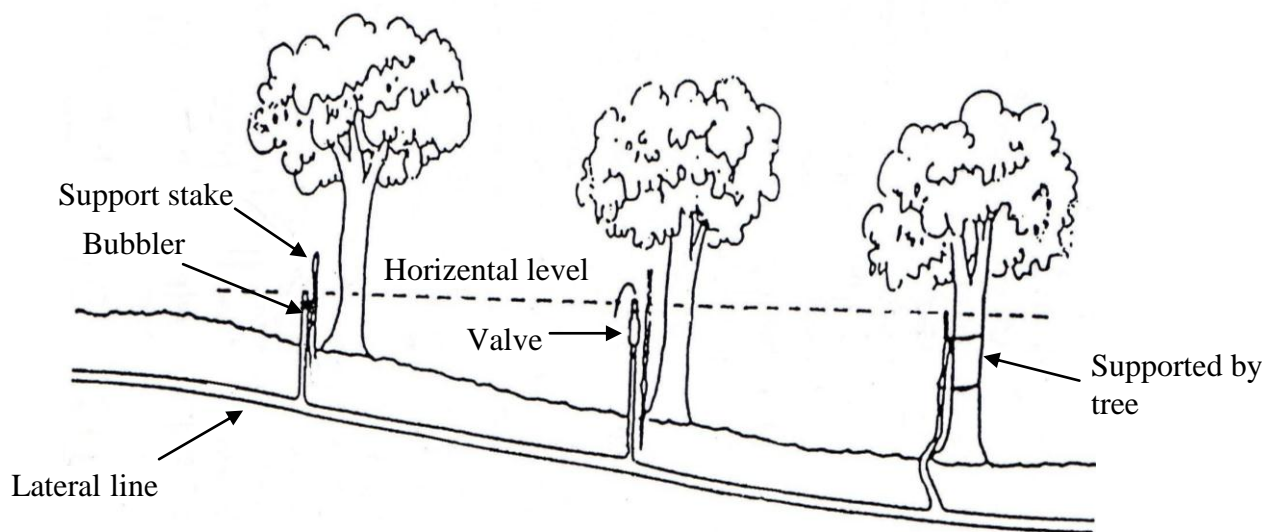


Figure (2.5): Diagram of bubbler irrigation system, (**Awady and Habib, 1992**).

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.

Table (2.4) shows recommended range of (*EU*) values. In fact, the above statement is not only for (*EU*), but it also applies to all other uniformity expressions. For microirrigation, which has a relatively high

uniformity in design, all the uniformity expressions can be converted and used for other uniformity expressions.

Table (2.4): Recommended ranges of design emission uniformity (*EU*) by (ASABE Standards, 2006).

Emitter type	Spacing, <i>m</i>	Topography	Slope,%	EU range,%
Point source on Perennial crops	>4	Uniform Steep or undulating	<2 >2	90 to 95 85 to 90
Point source on Perennial or semi- permanent crops	<4	Uniform Steep or undulating	<2 >2	85 to 90 80 to 90
Line source on annual or Perennial crops	All	Uniform Steep or undulating	<2 >2	80 to 90 70 to 85

3. MATERIALS AND METHODS

The experimental work was conducted at the Farm of Agriculture Faculty, Suez Canal University, Ismailia, Egypt from November, 2008 to August, 2009.

Two groups of experiments were carried out in this study. The first was the laboratory experiment carried out in the hydraulics laboratory of Agricultural Engineering Department to determine bubbler discharge exponent constants and manufacturer's coefficient of variation for three bubbler tube outlet. The second was the field experiment which carried out to, 1-evaluate the effect of different initial operating pressure and bubbler tube diameters on bubbler discharge uniformity, 2-determining the optimum height of each bubbler diameter which achieves the highest bubbler uniformity to calibrate the bubbler height equation.

3.1. Instruments for Laboratory and Field Experiments

- Graduated cylinder of one liter capacity with an accuracy of 10 cm^3 was used to measure the water volume discharge. A stop watch was used to measure the elapsed time in different operations.
- A steel tape of one meter length was used to determine the bubbler height.
- Electronic digital calipers with accuracy of 0.01 mm was used for measuring the inside diameter of the bubbler tubes.
- Pressure gauge range (0.6 bar) with 0.02 bar increment scale.
- Electrical Drill and pincer used to perforate the lateral pipes to mount the bubbler tubes.

3.2. Laboratory Experiments

Laboratory experiments were carried out to find the discharge of water from different bubbler diameter types and pressures to determine the bubblers constants. The discharges of bubblers were measured along lateral pipe at different pressures. Pressure head was measured in laboratory experiment by pesometric tube with 1 *cm* increment scale. The tested pressures were 11 to 20 *kPa* with an increment of (1 *kPa*).

3.3. Field Experiments

The completely randomized factorial design of 3 bubbler tube diameters time's 3 pressure levels in three replications was used with the following variables as shown in Figure (3.1). Before starting the experiments, air in the lateral was flushed out by opening its downstream end. Pressures were set at (15, 30 and 45 *kPa*), and the bubbler discharges were measured by collecting the water volume in plastic container in 5 minutes. The experiment was executed on the level ground surface. Specific bubbler flow functions, such as pressure flow relationship and manufacture coefficient of variation, coefficient of uniformity and bubbler heights were determined.

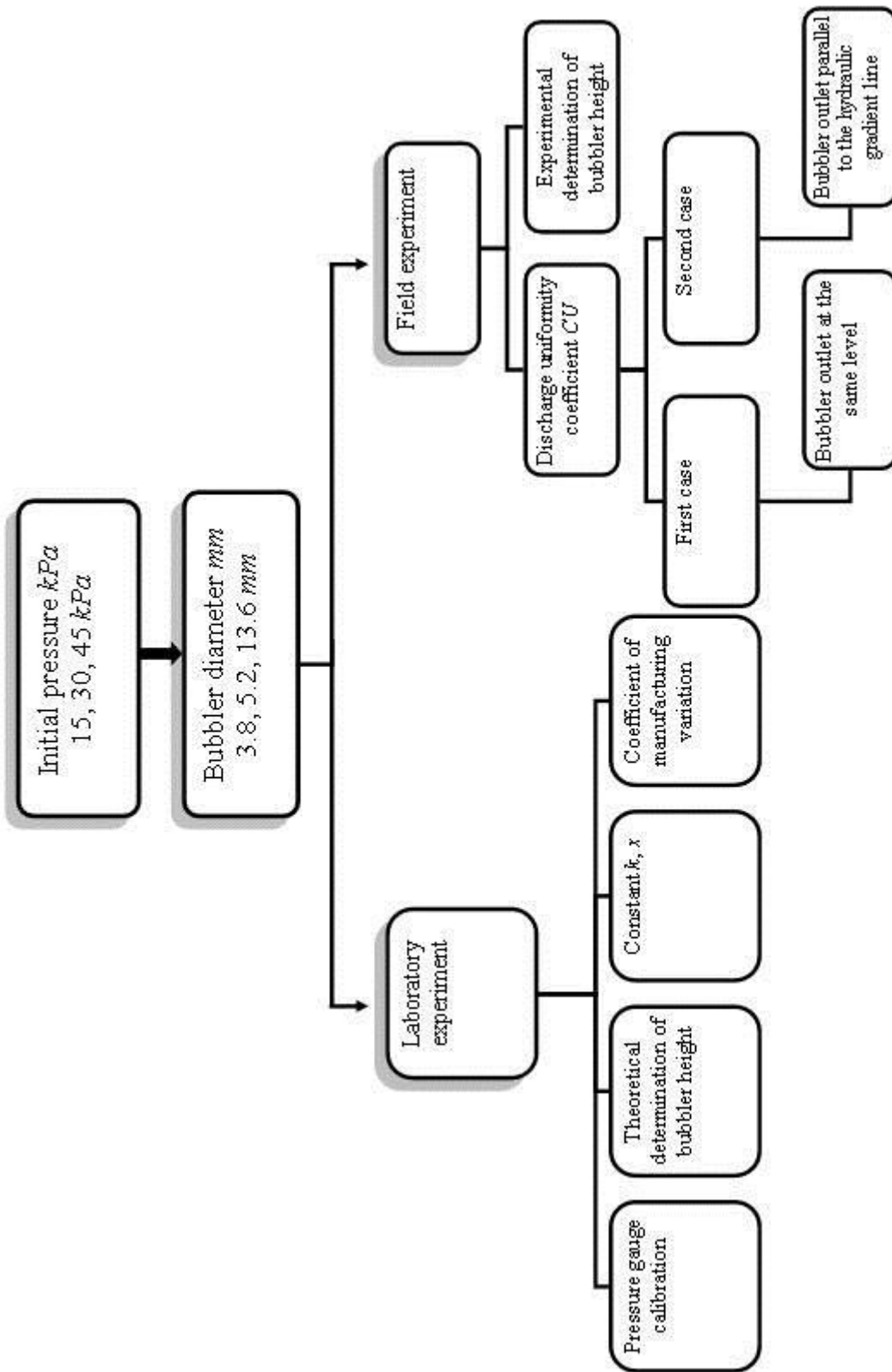
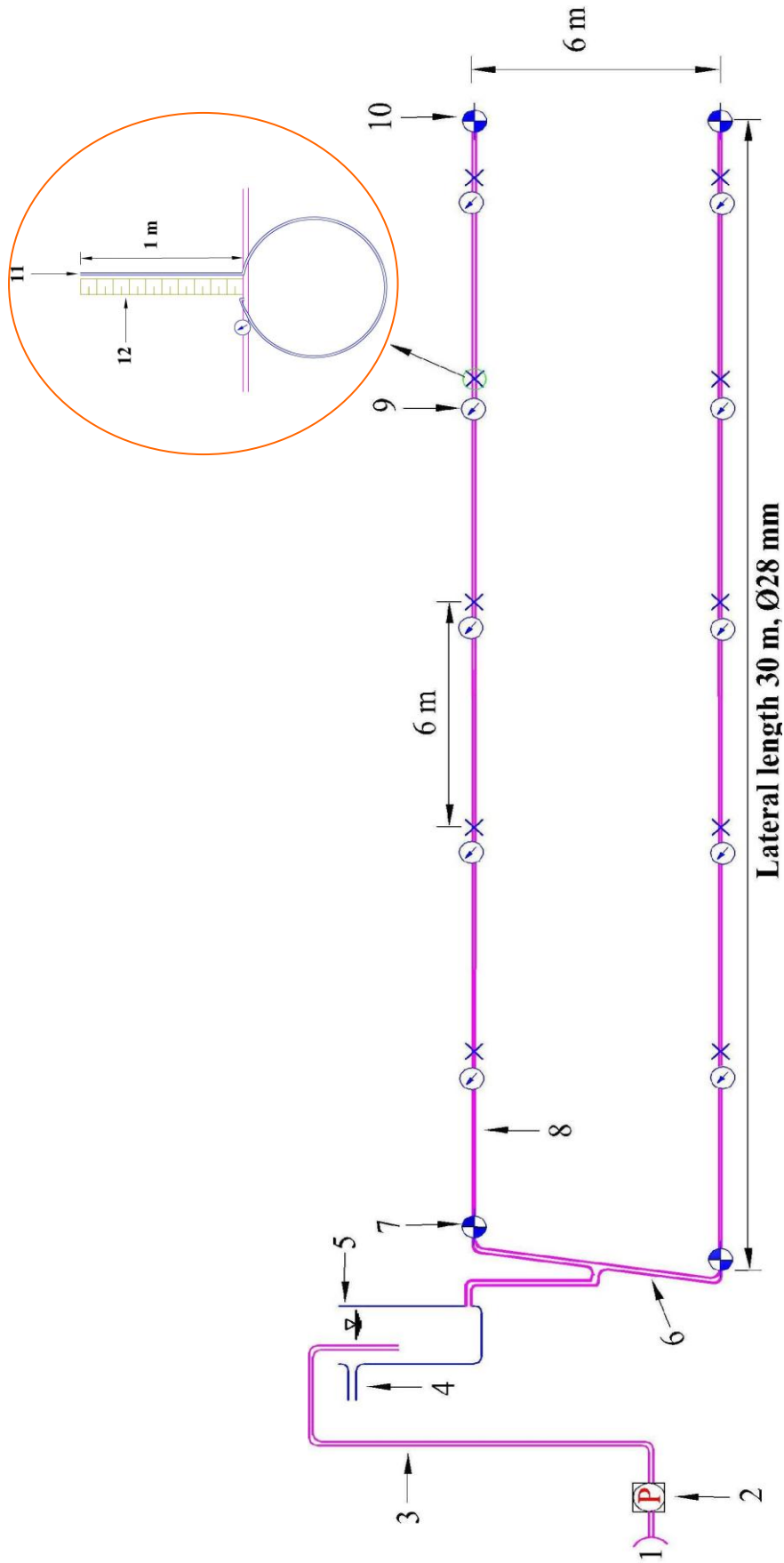


Figure (3.1): The experimental work flowchart.

3.3.1. The experimental setup

The experimental bubbler irrigation system shown in Figure (3.2) and (3.3) can be described as follows

1. The water is pumped from the water source by using self priming centrifugal pump, suction-orifices diameter: 38.1 *mm* and delivery-orifices diameter: 31.8 *mm* which powered by electric motor 3 horse Power (2.2 *KW*), 220 volts.
2. 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.
3. The water level was kept constant in the tank by using an over flow tube with diameter 50 *mm*.
4. 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 (*ID*, 28 *mm* internal diameter). The lateral pipe slope is zero.
5. 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* were 3.8, 5.2 and 13.6 *mm*, respectively the length of each bubbler was 5 *m* as shown in Figure (3.2). The bubbler was tide to wooden stakes substituted of tree trunk.
6. Pressure gauges were mounted before each bubbler inlet to measure the pressure.



- | | | |
|---------------------|------------------|--------------------|
| 1- Water source | 5-Tank | 9- Pressure gauge |
| 2- Centrifugal pump | 6- Sub main pipe | 10- Flushing valve |
| 3- Delivery tube | 7- Valve | 11- Bubbler tube |
| 4- Over flow tube | 8- Lateral pipe | 12- Steel tape |

Figure (3.2): The experimental setup diagram.

3.3.2. Performance and evaluation of bubblers

3.3.2.1. Pressure- flow relationships

For studying the hydraulic performance, bubbler discharge was measured at three initial operating pressures “ P_i ” (15, 30 and 45 kPa). Bubbler flow as a function of pressure can be expressed as (Wu & Gitlin, 1973; Howell & Hiler, 1974; Keller & Karmeli, 1974 and ASAE Standards 2003):

$$q = k h^x \quad (3.1)$$

Where:

q : Bubbler discharge rate, ℓ/h

k : The constant of proportionality that characterizes each emitter,

h : working pressure head at the emitter, m and

x : The emitter discharge exponent that is characterized by flow regime.

The magnitude of (k) is a size or capacity parameter for a bubbler since its value is equal to the bubbler flow rate when (h) equals unity (Howell and Hiler, 1974). The suggested criteria for (x) values were presented in Table (2.2).

A different effective pressure (P_e) from (11 to 20 kPa) with an increment (1 kPa) was used for bubbler system under investigation. The effective pressure was obtained by changing the bubbler height. The discharge was measured at each effective pressure by receiving the water from the determine bubbler in plastic container through equal period, and then the discharge was measured by using measuring cylinder. The last experiment was repeated for each bubbler. The values of parameters (k)

and (x) were determining by power regression between measured (q) versus effective pressure (P_e).

The following equation was used to calculate the percentage of discharge difference as follows

$$q_c = \left[\frac{q_{pe} - q_{med}}{q_{med}} \right] \times 100 \quad (3.2)$$

Where:

q_c : Percentage of discharge changing from medium value of discharge, %

q_{pe} : Bubbler discharge at any effective pressure P_e , ℓ/min and

q_{med} : Bubbler discharge at medium value of effective pressure and the same water temperature degree, ℓ/min .

The percentage of uniformity difference calculated by the following equation:

$$Cu_c = \left[\frac{Cu_{pe} - Cu_{med}}{Cu_{med}} \right] \times 100 \quad (3.3)$$

Where:

Cu_c : Percentage of uniformity coefficient changing from medium value of uniformity coefficient, %

Cu_{pe} : Bubbler uniformity coefficient at any effective pressure P_e , ℓ/min and

Cu_{med} : Bubbler uniformity coefficient at medium value of effective pressure and the same water temperature.

3.3.2.2. Bubbler manufacturer's coefficient of variation C_v .

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

$$C_v = \frac{S}{\bar{x}} \quad (3.4)$$

Where:

C_v : Manufacturer's coefficient of variation (Dimensionless)

S : Standard deviation of bubbler discharge (ℓ/h) in the sample was determined according to equation (3.5) and

\bar{x} : Mean discharge of bubblers, ℓ/h .

$$s = \left[\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1} \right]^{1/2} \quad (3.5)$$

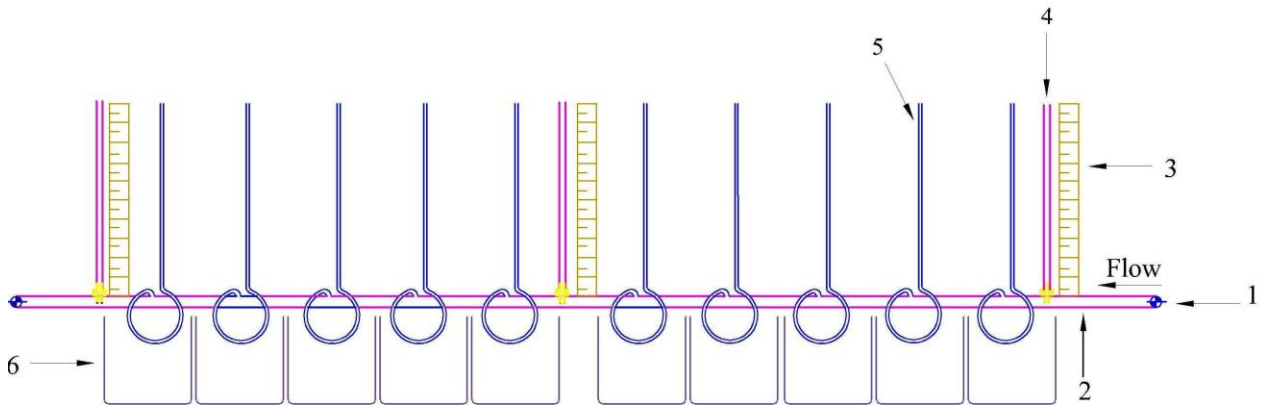
Where:

x_i : Discharge of an bubbler and

n : Number of bubblers.

The experimental work was done with no plugging at the same hydraulic design and temperature. So that, the average bubbler discharge variation was caused by bubbler manufacturing variation. The manufacture coefficient variation ranges from 0.05 to 0.2 for different emitter and lateral lines (**Bralts, 1978 and Solomon, 1979**).

Ten bubbler tubes were tested for each bubbler diameter to determine (C_v), three piezometer tubes used to monitor the pressure in the lateral pipe at the first, middle and the end of lateral pipe as shown in Figure (3.3).



- | | | |
|----------------|--------------------|----------------------|
| 1-Valve | 3-Steel tape | 5- Bubbler tube |
| 2-Lateral pipe | 4- Piezometer tube | 6- Plastic collector |

Figure (3.3): Setup diagram of manufacturer's coefficient of variation test.

3.3.2.3. Bubblers discharge uniformity coefficient C_u .

The uniformity of irrigation water was calculated in this study in two different cases when the bubbler outlets at equal elevation and the bubbler outlets parallel to the hydraulic gradient line. The Christiansen uniformity coefficient (C_u) was calculated by **Perold (1977)** bubbler irrigation system equation as follows:

$$C_u = (1 - |\bar{\sigma}|) \times 100 \quad (3.6)$$

Where:

C_u : Coefficient of uniformity, % and

$|\bar{\sigma}|$: Absolute mean deviation of discharge on lateral pipe.

The absolute mean deviation $|\bar{\sigma}|$ is calculated from the following equation:

$$|\bar{\sigma}| = \frac{\sum q - \bar{q}}{n} \quad (3.7)$$

Where:

n : Number of bubblers

\bar{q} : Mean discharge, equal to $\frac{\sum q}{n}$ and

q : Discharge from bubbler.

In this study the discharge uniformity was calculated for each bubbler along the lateral pipe at different initial operating pressure of (15, 30 and 45 *kPa*).

3.3.2.3.a. Bubbler outlets at equal elevation

The goal of this experimental work (when the bubbler outlet at equal elevation) as shown in Figure (3.4) is determining the effect of different initial and operating pressure (P_o) on bubbler discharge and discharge uniformity. Three initial operating pressures (P_i) (the distance between the water level in the tank and ground level), of 15, 30 and 45 *kPa*. Six operating pressure (P_o) (the distance between the bubbler outlet height and the water level in the tank) were determined by bubbler height of (0.0, 0.2, 0.4, 0.6, 0.8 and 1.0 *m*) in each initial operating pressure. Figure (3.5) illustrate the experimental design of the uniformity in first case which completely randomize factorial design $6 \times 3 \times 3 \times 1$ in three replicates. Five plastic collectors, (60) litter capacity located under the bubblers to collect the discharged water from each lateral pipe. The bubbler discharge measured by receiving a volume of water at specified time by stop watch.

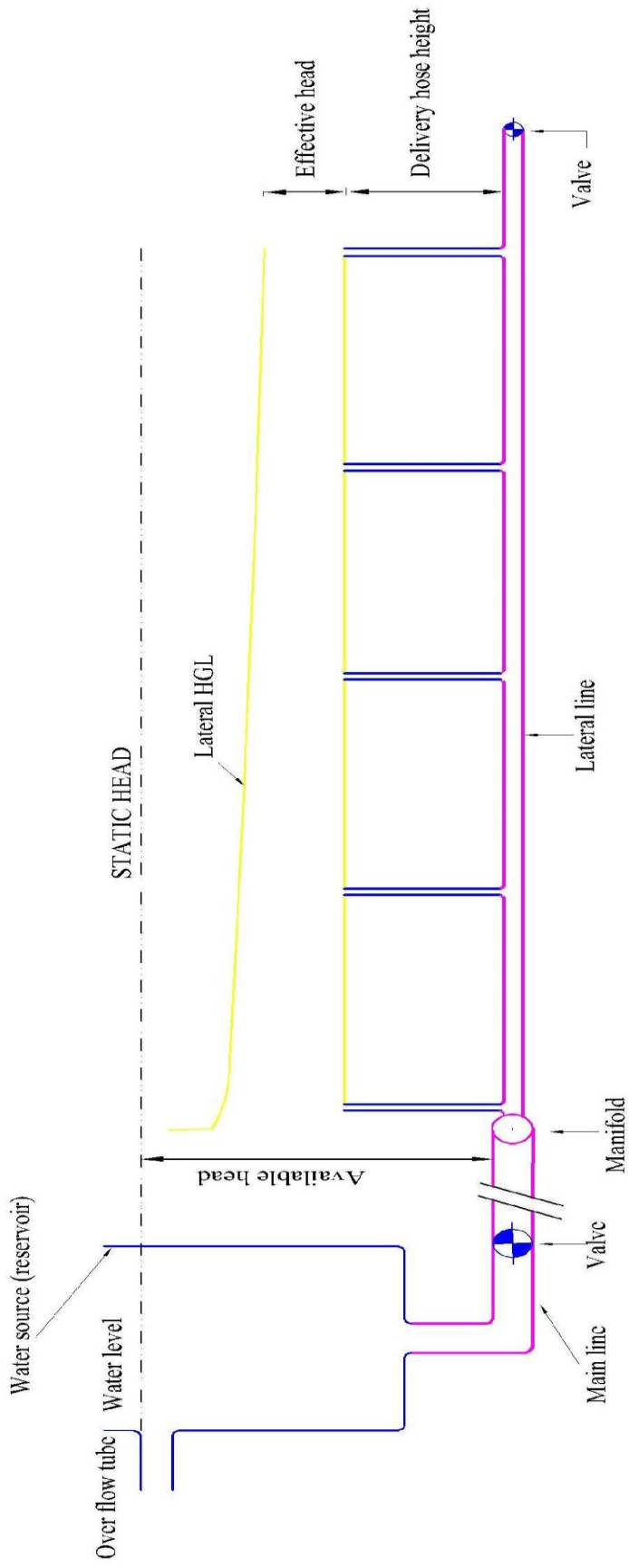
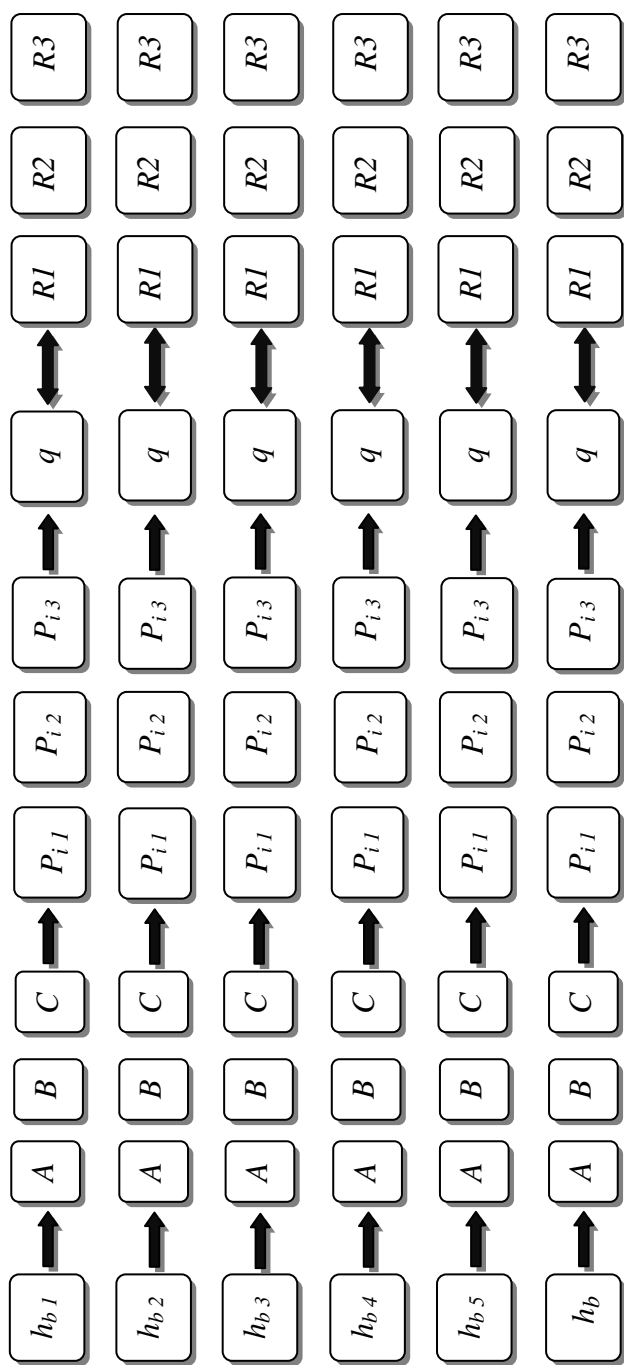


Figure (3.4): Bubbler systems (first case).



h_b : Bubbler height, m

A, B, C : Bubbler tube diameters (3.8, 5.2 and 13.6 mm), respectively,

P_i : initial operating pressures, (15, 30, 45 kPa)

q : Discharge for each bubbler tube diameter, ℓ/min and

$R1, R2, R3$: Replications.

Figure (3.5): The experimental design for the uniformity in (first case).

3.3.2.3.b. Bubbler outlet parallel to hydraulic gradient line

As mentioned before the ground surface was level, so the hydraulic gradient line was determined by measuring the pressure at each bubbler inlet to know the friction losses along the lateral pipe. Then the bubbler tubes outlet height calculated to be parallel to the hydraulic gradient line as shown in Figure (3.6). Three effective pressures or operating pressures (the distance between hydraulic gradient line and level of bubblers outlets) were chosen. Figure (3.7) illustrate the uniformity in (second case) which completely randomize factorial design $3 \times 3 \times 3 \times 1$ in three replicates. The predetermined effective pressures were chosen depending on the highest values of discharge uniformity in experiment of the bubbler outlets at equal elevation.

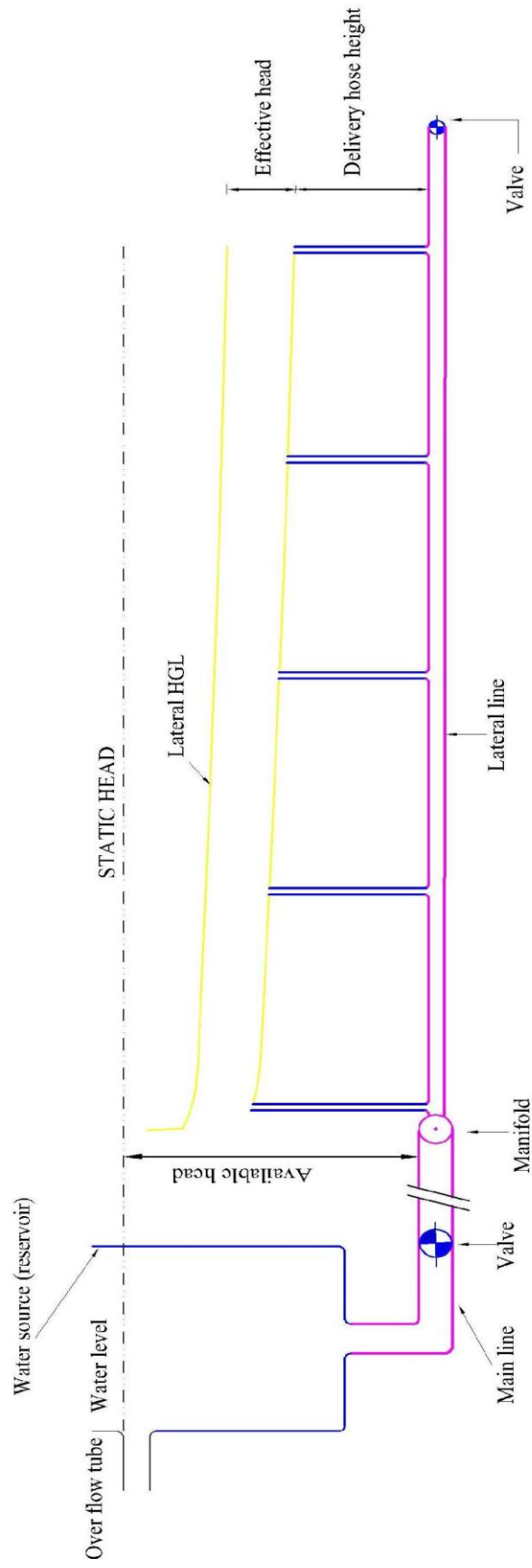
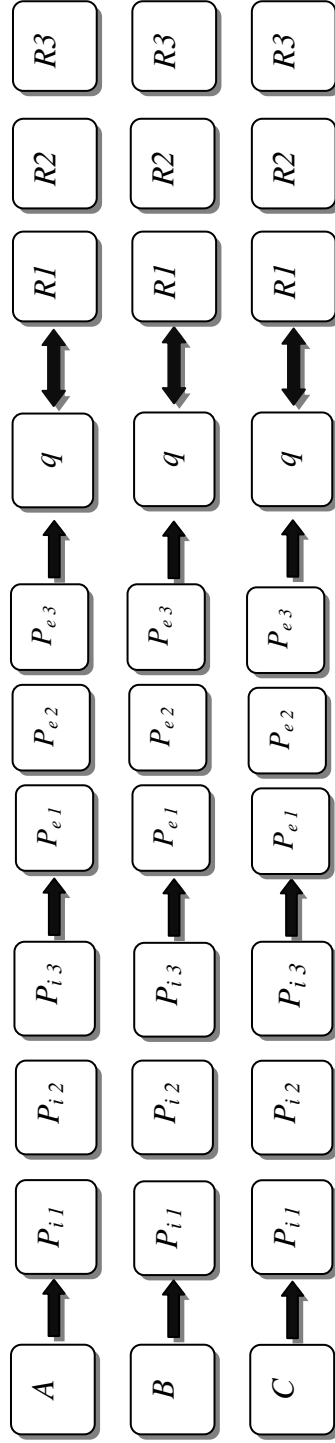


Figure (3.6): Bubbler systems (second case).



A, B, C: Bubbler tube diameters, (3.8, 5.2 and 13.6 mm)

P_i: initial operating pressures, (15, 30, 45 kPa)

P_e: Effective pressure, kPa

q: Discharge for each bubbler tube diameter, ℓ/min and

R1, R2, R3: Replications.

Figure (3.7): The experimental design for the uniformity in (second case).

3.3.3. Determination of bubbler height for specified bubbler discharge

To achieve high bubblers discharge uniformity on lateral pipe two methods were used:

First: by controlling the cross section area of bubblers.

Second: by adjusting the bubbler height on the lateral pipe.

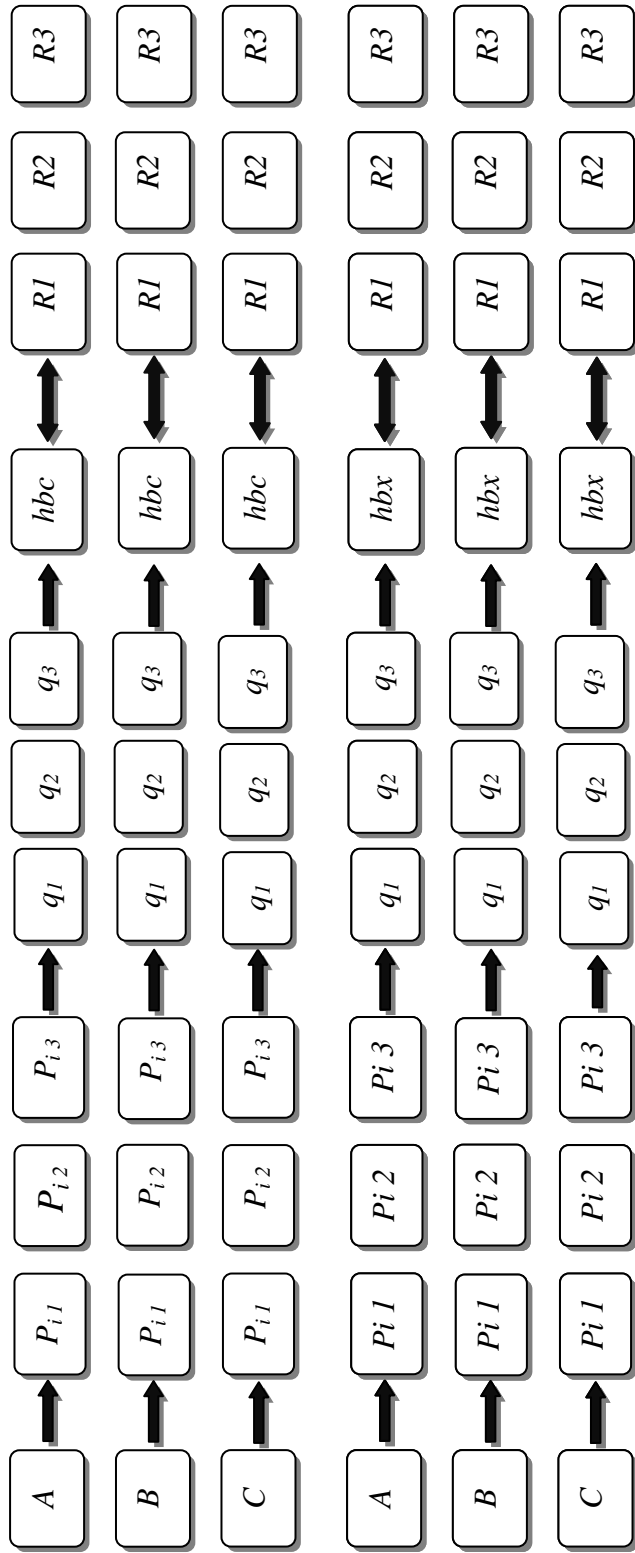
In order to determine the bubbler height on lateral pipe for specified bubbler tube diameter, a general equation was derived from several equations of microirrigation systems design.

To verify the general equation, a practical experiment was done. The analysis of variance using t-test was used to determine the significance between calculated and experimental results. Figure (3.8) illustrate the experimental design for calculated and experimental bubbler height which completely randomize factorial design $3 \times 3 \times 3 \times 1$ in three replicates.

3.3.3.1. Theoretical method

The bubbler height (h_b) parallel to hydraulic gradient line, it's depends on several variables which could be classified as:

- Design parameters such as: length (L), diameter (D) and coefficient of friction (F) of lateral pipe, and length (l), location (l_i), diameter (d), coefficient of friction (f_i) of bubbler tube and distance between bubblers (s).



A, B, C: Bubbler tube diameters, (3.8, 5.2 and 13.6 mm)

P_i: Initial operating pressures, (15, 30, 45 kPa)

q: Bubbler tube discharge, ℓ/min

hbc: Calculated bubbler height, and

hbx: Experimental bubbler height.

R1, R2, R3: Replications.

Figure (3.8): The experimental design for bubbler height determination.

- Operating parameters such as: Lateral pipe discharge (Q), bubbler discharge (q) and initial operating pressure (P_i) Therefore the bubbler height (h_b) can be expressed as function of these variables as follows:

$$h_b = f_1(L, D, F, L, l_i, d, f_i, s, Q, q, H_i) \quad (3.8)$$

In order to define the function (f_1), the bubbler system this shows in Figure (3.7) is considered concerning the following assumptions:

1. An equal bubbler discharge (q), which is the aim of any bubbler irrigation system.
2. An equal bubbler discharge could be reached by an equal effective pressure (P_e).
3. Drawing a curve parallel to the bubblers outlets line by a distance equal to the (P_e) leads to the gradient of bubbler height as shown in Figure (3.6).
4. The regime flow in lateral pipe is turbulent.
5. Materials of lateral pipe and bubblers tubes are polyethylene.

For the investigated system, the distance between bubblers (s) was equal to a distance from water source to the first bubbler; therefore the final equation could be expressed as following **Abozaid et al. (1998)**:

$$hbn = H_i - \left(\frac{q}{k}\right)^{\left(\frac{1}{x}\right)} - \left(61111 \times q^{1.75} \times D^{-4.75} (s + cl) \sum_{n=1}^N (N - n + 1)^{1.75} \right) \quad (3.9)$$

Where:

hbn : Bubbler height of a bubbler number n , cm

H_i : Initial head, cm

q : Bubbler discharge, ℓ/\min

k, x : Constants;

D : Lateral pipe inside diameter, mm

S : Distance between two sequence bubblers, m

Cl : Bubbler inlet barb equivalent length, m and

N : Total number of bubblers.

For the investigated system minor losses are found in bubblers inlet barbs. The bubbler inlet losses should be substituted by equivalent length (cl) as indicated by **James (1988)** as follows:

$$Cl = 1.729 D^{-1.935} \quad (3.10)$$

Where:

Cl : Bubbler inlet barb equivalent length, m and

D : Diameter of lateral pipe, cm .

Therefore, the distance between bubblers in the final equation of bubbler height was substituted by ($s + cl$).

3.3.3.2. Final equation of bubbler height validation

To test predetermined bubbler height by equation (3.9), the hydraulic gradient line was drawn by using pressure gauges at bubbler inlets with same bubbler outlet levels. Secondly, the effective pressure was calculated then the bubbler discharge was measured at this effective pressure, additionally two more up and down this effective pressure were experienced.

3.3.4. Pressure gauge calibration

Pressure gauges were laboratory calibrated by using Piezometric tube. The experiment setup consists of 32 mm nominal diameter (ID 28 mm) as a lateral pipe with two valves in the inlet and outlet to control the water pressure, 3 m height piezometric tube mounted on the center of lateral pipe with steel tape 0.5 cm increment scale used to measure the pressure. Calibrated pressure gauge was connected next to piezometric tubes as shown in Figure (3.9). The true reading was obtained from the piezometric tube and the indicated reading was obtained from the pressure gauge. Then the relationship between indicated and true value was obtained by spread sheet to get the percentage of error for each pressure gauge.

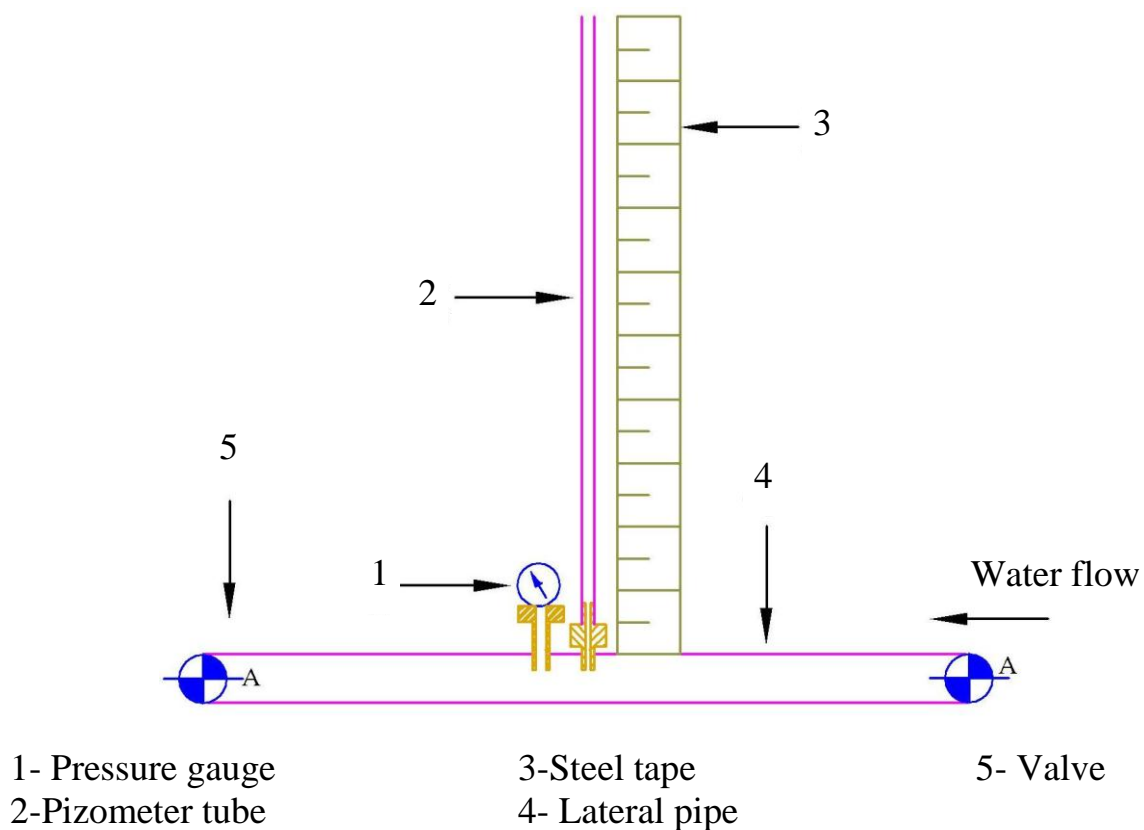


Figure (3.9): Pressure gauge calibration setup diagram.

The percentage of error was calculated for each pressure gauge by the following equation:

$$\text{Percentage of error} = \frac{\text{indicated value} - \text{true value}}{\text{Maximum scale value}} \times 100 \quad (3.11)$$

3.3.5 Software and programs used in the study

We used different methods, programs and software to analysis the data in this study. First the statistical analysis which use in this study was T-Test (in groups) (**Steel *et al.*, 1996**). Second **AutoCAD** is a CAD (Computer Aided Design) software application for *2D* and *3D* design and drafting (**Byrnes, 2007**).

4. RESULTS AND DISCUSSION

In this chapter the results displayed bubbler hydraulic performance for three bubbler tube diameters 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) and finally,
- Bubbler tube height.

4.1. Laboratory Experiments

4.1.1. Effect of operating pressure on discharge

Three bubbler tube internal diameters have been used in this study. They were 3.8, 5.2 and 13.6 *mm*. Each of them was tested with operating pressure from (11 to 20 *kPa*) by increment (1 *kPa*).

Table (4.1) and Figure (4.1) shows the discharge of each bubbler tube diameter for all operating pressure. Bubbler discharge proportionally increased with increasing the operating pressure for all bubbler tube diameters. Due to increasing the operating pressure from (11 to 20 *kPa*), 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 (4.1): The bubbler discharge and manufacturer's coefficient of variation for different effective pressure and bubbler tube diameters.

Mean effective pressure P_e , (KPa)	(\emptyset) ID 3.8 mm		(\emptyset) ID 5.2 mm		(\emptyset) ID 13.6 mm	
	Mean discharge (ℓ/min)	C_v	Mean discharge (ℓ/min)	C_v	Mean discharge (ℓ/min)	C_v
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

Figure (4.1) and Table (4.2) show the relation between bubbler discharges versus effective pressures. 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 (Boswell, 1985).

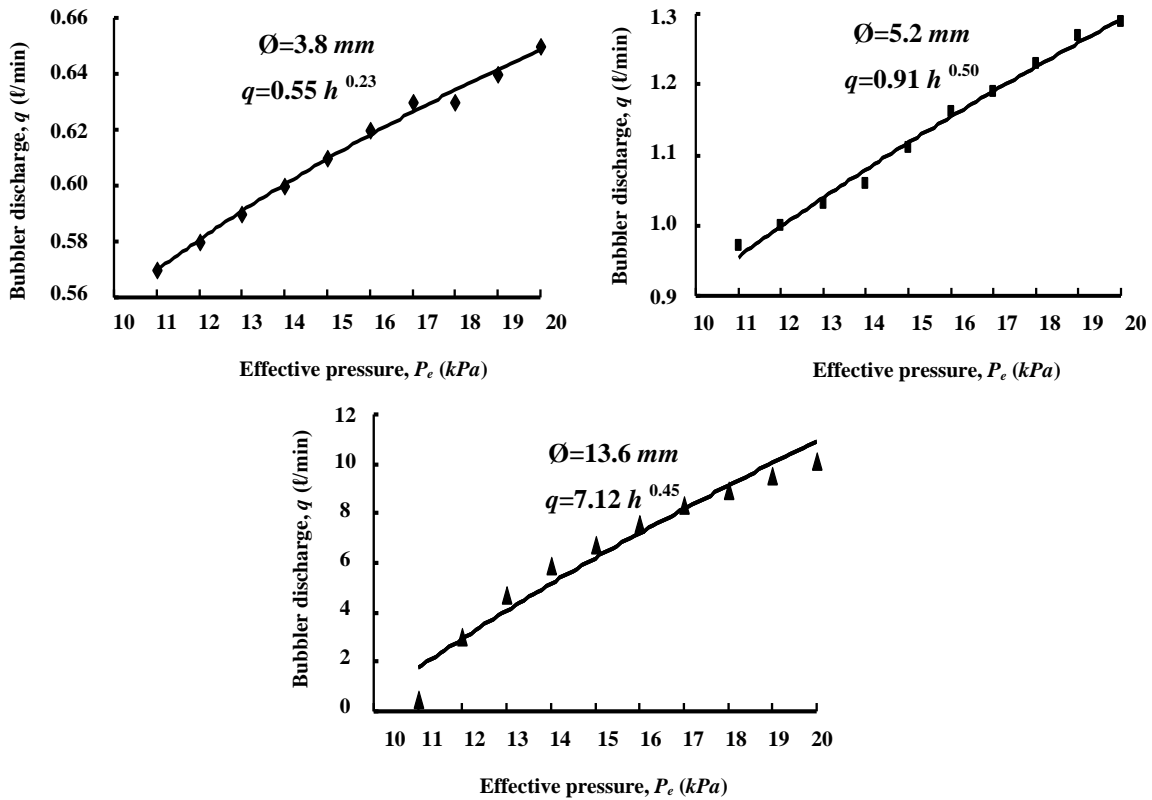


Figure (4.1): Relationship between effective pressure and bubbler discharge for different bubbler tube diameters.

Table (4.2): The bubbler discharge equation parameters and correlation coefficient for different bubbler tube diameters.

Bubbler diameter, (mm)	k	χ	R^2
3.8	0.55	0.23	0.99
5.2	0.91	0.50	0.99
13.6	7.12	0.45	0.95

4.1.2. Bubbler manufacturer's coefficient of variation C_v .

Table (4.1) and Figure (4.2) show the manufacturing coefficient of variation's (C_v) for each bubbler diameter. C_v values of the three bubbler diameters were ranged between 0.003 to 0.011 at 11 to 20 kPa effective pressure, respectively which considered excellent according to the

classification of manufacturing variation coefficient for point source which recommended by **ASAE Standards (2000)**.

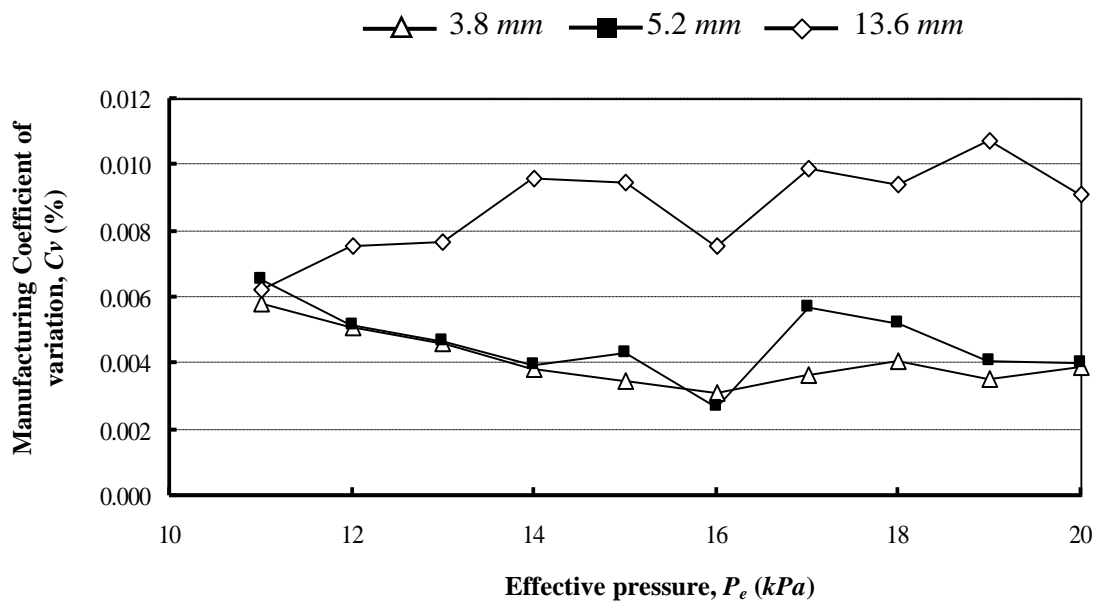


Figure (4.2): The relation between effective pressure and manufacture coefficient of variation of different bubbler diameters.

The (C_v) values were fluctuated for the three bubbler tube diameters with effective pressures increasing, these results have a good agreement with **El lithy (1998)** and **Hussein (2007)**.

4.2. Field Experiments

Two field experiments were carried out. The purpose of the first experiment was carried out to find the highest value of discharge uniformity coefficient (C_u) of different heights with several pressures, in each bubbler tube diameter

The goal of the second experiment was to test the highest uniformity at equal outlet elevation, and then apply this highest

uniformity to state of bubbler outlet parallel to the hydraulic gradient line. In the end, a theoretical bubbler height equation was validated.

4.2.1. Discharge uniformity coefficient Cu .

4.2.1.a. The outlet at equal elevation (first case)

Table (4.3) and (A.1) in the appendix show the Christiansen uniformity coefficient (Cu) for the three bubbler tubes diameter at equal outlet elevations.

i.) Bubbler heights (0.0 m)

The mean effective pressure (P_e) and the mean discharge were proportionally increased with initial operating pressure (P_i) increasing for all bubbler tube heights and diameters. Where (P_e) values were 7.02, 24.38 and 40.46 kPa for 3.8 mm bubbler tube diameter at (P_i) 15, 30 and 45 kPa , Figure (4.3.A) whereas at initial operating pressures 15, 30 and 45 kPa the discharge (q) values were 0.51, 0.68 and 0.76 ℓ/min , the discharge uniformity (Cu) values were 98.8, 98.8 and 98.2%, respectively as shown in Figures (4.4.A) and (4.5.A). It was found that the discharge uniformity coefficient (Cu) values were relatively constant with different initial operating pressures for all bubbler tube heights.

Meanwhile for 5.2 mm bubbler tube diameter, (P_e) values were 12.96, 24.82 and 35.58 kPa at (P_i) 15, 30 and 45 kPa , as shown in Figure (4.3.B). The discharge (q) values were 1.03, 1.43 and 1.72 ℓ/min and the discharge uniformity (Cu) values were 94.4, 99.2 and 96.8% at initial operating pressures 15, 30 and 45 kPa , respectively as shown in Figures (4.4.B) and (4.5.B). The discharge uniformity coefficient values were increased with increasing the initial operating pressure from 15 to 30 kPa and decreased with increasing the initial operating pressure from 30 to 45 kPa for all bubbler tube heights.

Table (4.3): Bubbler mean effective pressures, discharge and uniformity at different initial operating pressures for internal bubbler diameters at the same bubbler heights (first case).

h_b m	ID, \emptyset mm	P_i kPa	mean effective pressure, P_e kPa	Mean discharge, q ℓ /min	Cu %	h_b m	ID, \emptyset 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

h_b : Bubbler height P_i : Initial operating pressures Cu : Discharge uniformity coefficient

Likewise, (P_e) values were 9.12, 15.72 and 21.04 kPa for 13.6 mm bubbler tube diameter, at (P_i) 15, 30 and 45 kPa, as shown in Figure (4.3.C). At initial operating pressures 15, 30 and 45 kPa the discharge (q) values were 6.83, 8.7 and 9.93 ℓ /min and the discharge uniformity (Cu) were 65.8, 56 and 54%, respectively as shown in Figures (4.4.C) and (4.5.C). The discharge uniformity coefficient value decreased with

increasing the initial operating pressure from (15 to 45 kPa) for all bubbler tube heights.

ii.) Bubbler height (0.2 m)

The mean effective pressure (P_e) values were 6.5, 23.4 and 38.3 kPa for 3.8 mm bubbler tube diameter, at (P_i) 15, 30 and 45 kPa , as shown in Figure (4.3.A). At initial operating pressures 15, 30 and 45 kPa the discharge (q) values were 0.50, 0.68 and 0.75 ℓ/min and the discharge uniformity (Cu) were 98.8, 98.8 and 98.0%, respectively as shown in Figures (4.4.A) and (4.5.A).

Similarly, the mean effective pressure (P_e) values were 12.12, 24.18 and 34.66 kPa for 5.2 mm bubbler tube diameter, at (P_i) 15, 30 and 45 kPa , as shown in Figure (4.3.B). At initial operating pressures 15, 30 and 45 kPa the discharge (q) values were 1.0, 1.42 and 1.7 ℓ/min and the discharge uniformity (Cu) were 94.4, 99.2 and 96.8%, respectively as shown in Figures (4.4.B) and (4.5.B).

Meanwhile, for 13.6 mm bubbler tube diameter the mean effective pressure (P_e) values were 8.64, 15.0 and 19.9 kPa , at (P_i) 15, 30 and 45 kPa , as shown in Figure (4.3.C). At initial operating pressures 15, 30 and 45 kPa the discharge (q) values were 6.66, 8.53 and 9.69 ℓ/min and the discharge uniformity (Cu) were 66.2, 56.8 and 54.4%, respectively as shown in Figures (4.4.C) and (4.5.C).

iii.) Bubbler height (0.4 m)

The mean effective pressure (P_e) was proportionally increased with initial operating pressures (P_i) increasing, whereas (P_e) values were 6.16, 22.76 and 36.34 kPa for 3.8 mm bubbler tube diameters, at (P_i) 15, 30 and 45 kPa , as shown in Figure (4.3.A). At initial operating pressures 15, 30

and 45 *kPa* the discharge (q) values were 0.49, 0.67 and 0.74 ℓ/min and the discharge uniformity (Cu) were 98.8, 98.8 and 98.2%, respectively as shown in Figures (4.4.A) and (4.5.A).

Meanwhile, the mean effective pressure (P_e) values were 11.84, 23.7 and 33.86 *kPa* for 5.2 *mm* bubbler tube diameter, at (P_i) 15, 30 and 45 *kPa*, as shown in Figure (4.3.B). At initial operating pressures 15, 30 and 45 *kPa* the discharge (q) values were 0.99, 1.40 and 1.68 ℓ/min and the discharge uniformity (Cu) were 94.6, 99.2 and 97.0%, respectively as shown in Figures (4.4.B) and (4.5.B).

Just like, for 13.6 *mm* bubbler tube diameter, the mean effective pressure (P_e) values were 8.1, 14.4 and 18.8 *kPa* at (P_i) 15, 30 and 45 *kPa*, as shown in Figure (4.3.C). At initial operating pressures 15, 30 and 45 *kPa* the discharge (q) values were 6.48, 8.39 and 9.45 ℓ/min and the discharge uniformity (Cu) were 66.8, 57.6 and 55.4%, respectively as shown in Figures (4.4.C) and (4.5.C).

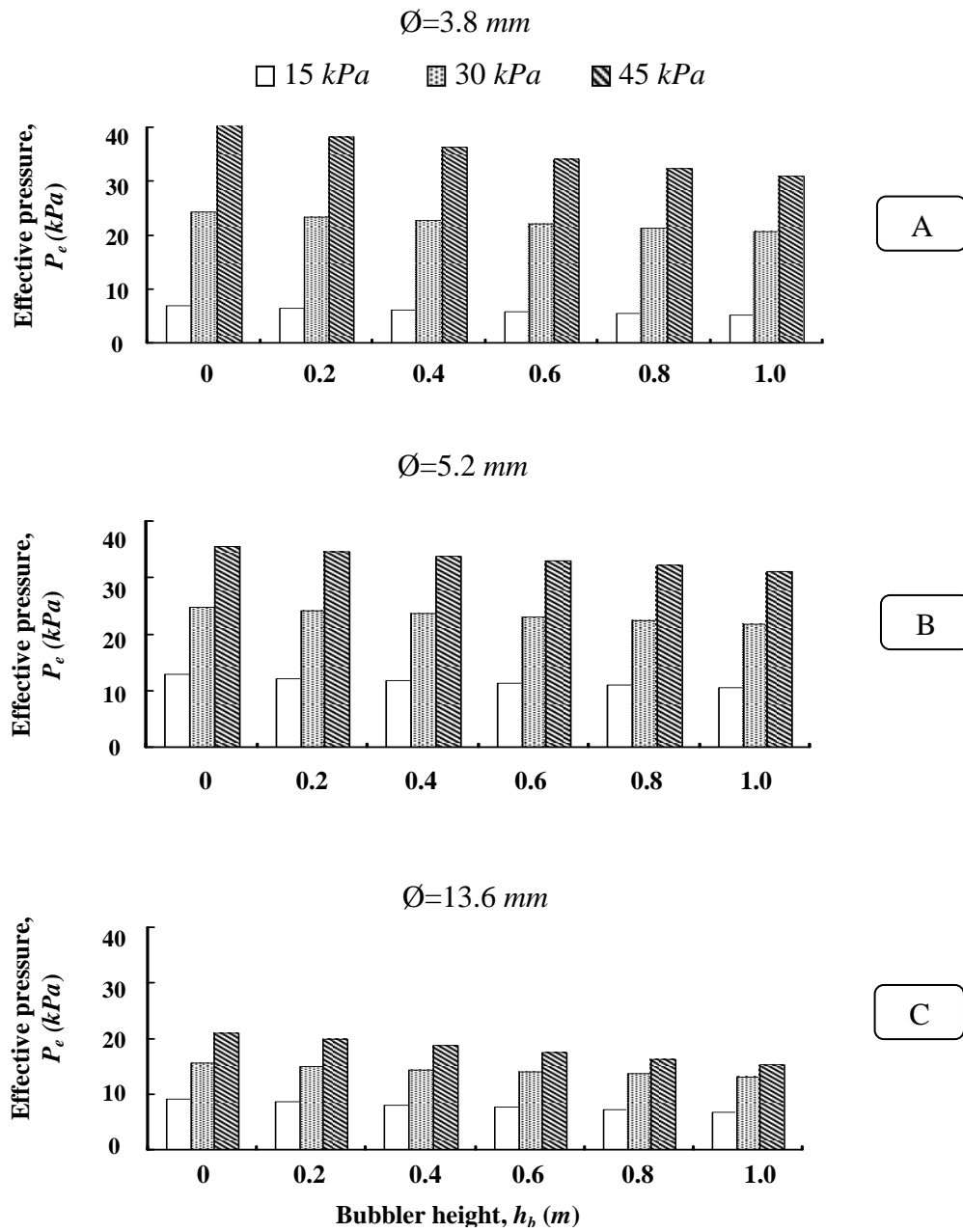


Figure (4.3): The relationship between bubbler height and effective pressure for different bubbler diameters and initial operating pressures (first case).

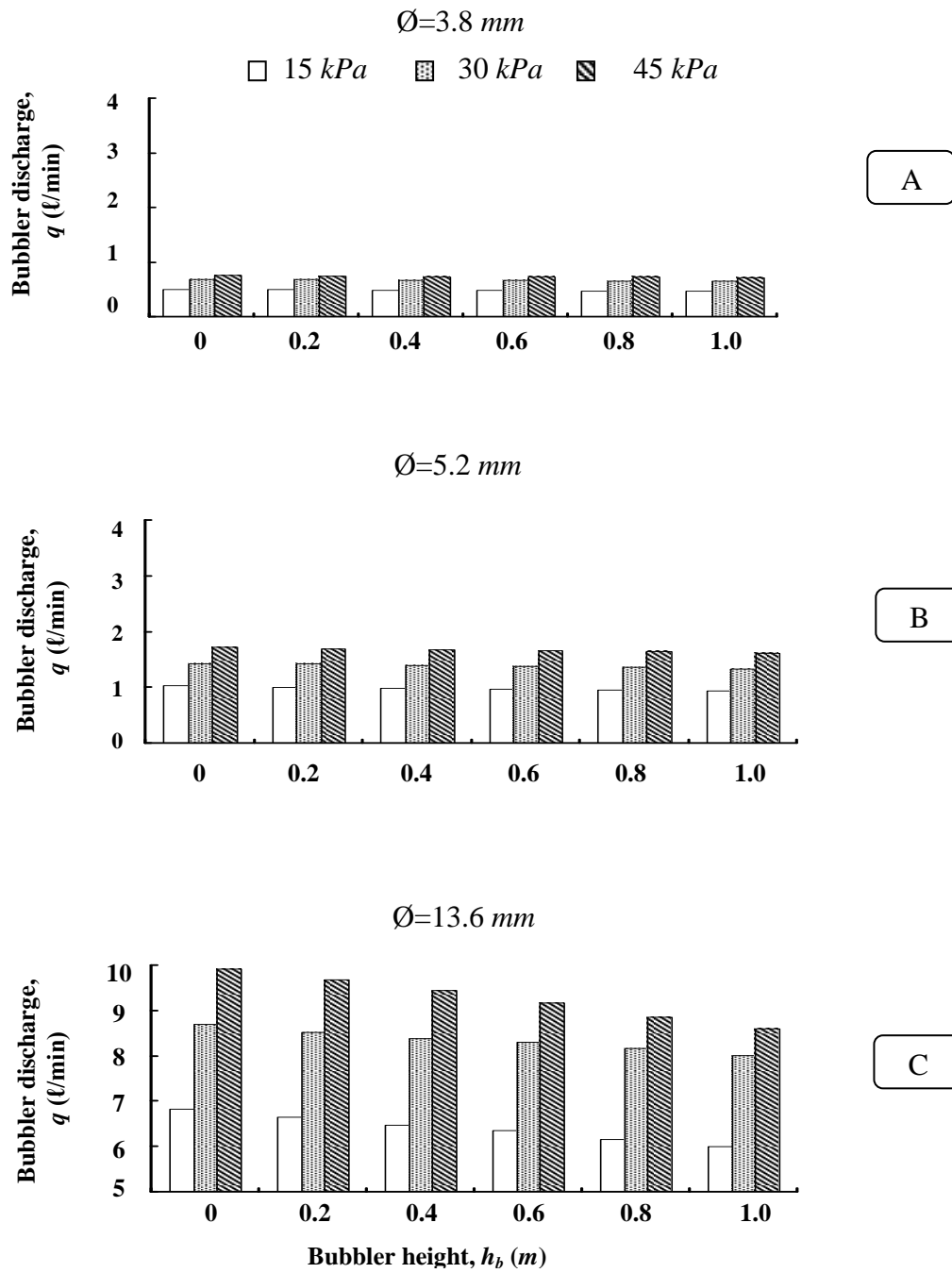


Figure (4.4): The relationship between bubbler height and bubbler discharge of different bubbler diameters and initial operating pressures (first case).

iv.) *Bubbler height (0.6 m)*

The mean effective pressure (P_e) values were 5.78, 22.06 and 34.1 *kPa* for 3.8 *mm* bubbler tube diameters, at (P_i) 15, 30 and 45 *kPa*, as shown in Figure (4.3.A). At initial operating pressures 15, 30 and 45 *kPa* the discharge (q) values were 0.49, 0.67 and 0.73 ℓ/min and the discharge uniformity (Cu) were 98.8, 98.8 and 98.0%, respectively as shown in Figures (4.4.A) and (4.5.A).

Another way to view this, the mean effective pressure (P_e) for 5.2 *mm* bubbler tube diameter, was proportionally increased with initial operating pressures (P_i) increasing, whereas (P_e) values were 11.44, 23.02 and 33.06 *kPa* at (P_i) 15, 30 and 45 *kPa*, as shown in Figure (4.3.B). At initial operating pressures 15, 30 and 45 *kPa* the discharge (q) values were 0.97, 1.38 and 1.66 ℓ/min and the discharge uniformity (Cu) were 94.6, 99.2 and 96.8%, respectively as shown in Figures (4.4.B) and (4.5.B).

Meanwhile, the mean effective pressure (P_e) values were 7.76, 14.06 and 17.6 *kPa* for 13.6 *mm* bubbler tube diameter, at (P_i) 15, 30 and 45 *kPa*, as shown in Figure (4.3.C). At initial operating pressures 15, 30 and 45 *kPa* the discharge (q) values were 6.35, 8.3 and 9.17 ℓ/min and the discharge uniformity (Cu) were 68.4, 58 and 55.4%, respectively as shown in Figures (4.4.C) and (4.5.C).

v.) *Bubbler height (0.8 m)*

The mean effective pressure (P_e) values were 5.5, 21.3 and 32.46 *kPa* for 3.8 *mm* bubbler tube diameter, at (P_i) 15, 30 and 45 *kPa*, as shown in Figure (4.3.A). At initial operating pressures 15, 30 and 45 *kPa* the discharge (q) values were 0.48, 0.66 and 0.73 ℓ/min and the discharge

uniformity (Cu) were 98.8, 98.8 and 98.4%, respectively as shown in Figures (4.4.A) and (4.5.A).

Like, for 5.2 mm bubbler tube diameter, the mean effective pressure (P_e) values were 11.02, 22.52 and 32.2 kPa at (P_i) 15, 30 and 45 kPa, as shown in Figure (4.3.B). At initial operating pressures 15, 30 and 45 kPa the discharge (q) values were 0.95, 1.37 and 1.64 l/min and the discharge uniformity (Cu) were 94.8, 99.0 and 96.8%, respectively as shown in Figures (4.4.B) and (4.5.B).

Meanwhile, the mean effective pressure (P_e) values were 7.24, 13.68 and 16.28 kPa for 13.6 mm bubbler tube diameter, at (P_i) 15, 30 and 45 kPa, as shown in Figure (4.3.C). At initial operating pressures 15, 30 and 45 kPa the discharge (q) values were 6.16, 8.17 and 8.85 l/min and the discharge uniformity (Cu) were 69.6, 58.6 and 55.8%, respectively as shown in Figures (4.4.C) and (4.5.C).

vi.) *Bubbler height (1.0 m)*

The mean effective pressure (P_e) values were 5.16, 20.74 and 30.92 kPa for 3.8 mm bubbler tube diameter, at (P_i) 15, 30 and 45 kPa, as shown in Figure (4.3.A). At initial operating pressures 15, 30 and 45 kPa the discharge (q) values were 0.47, 0.66 and 0.72 l/min and the discharge uniformity (Cu) were 98.8, 98.8 and 98.4%, respectively as shown in Figures (4.4.A) and (4.5.A).

Similarly, for 5.2 mm bubbler tube diameter, the mean effective pressure (P_e) values were 10.56, 21.8 and 31.18 kPa at (P_i) 15, 30 and 45 kPa, as shown in Figure (4.3.B). At initial operating pressures 15, 30 and 45 kPa the discharge (q) values were 0.94, 1.34 and 1.61 l/min and

the discharge uniformity (C_u) were 95.6, 99.4 and 96.2%, respectively as shown in Figures (4.4.B) and (4.5.B).

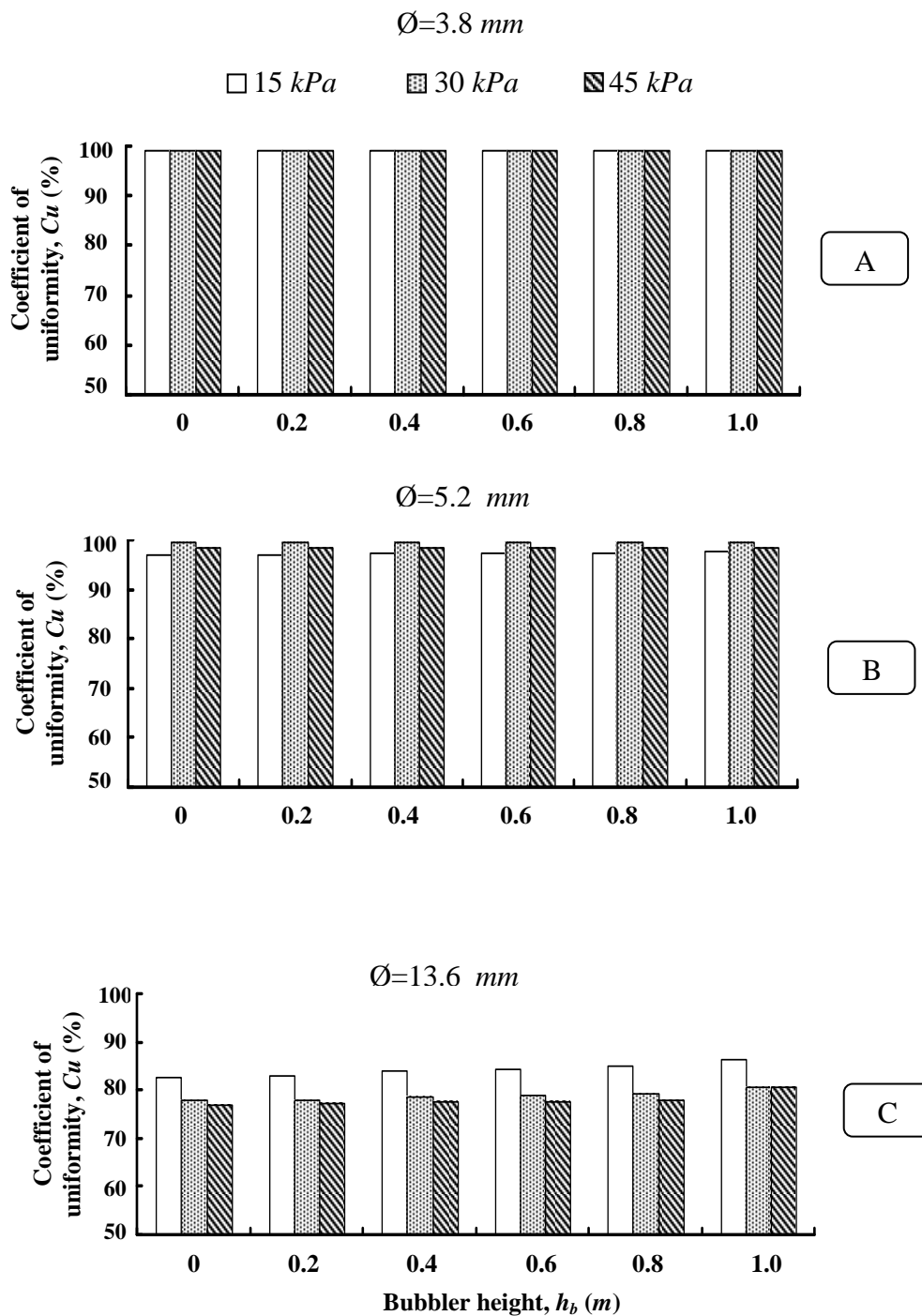


Figure (4.5): The relationship between bubbler height and coefficient of uniformity of different bubbler diameters and initial operating pressures (first case).

Meanwhile, the mean effective pressure (P_e) values were 6.48, 13.08 and 15.4 kPa for 13.6 mm bubbler tube diameter, at (P_i) 15, 30 and 45 kPa , as shown in Figure (4.3.C). At initial operating pressures 15, 30 and 45 kPa the discharge (q) values were 6.0, 8.02 and 8.61 ℓ/min and the discharge uniformity (Cu) were 72.8, 62.2 and 61.8%, respectively as shown in Figure (4.4.C) and (4.5.C).

Finally it can be seen that the mean effective pressure (P_e) 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, as shown in Figures (4.6) and (4.7). The mean effective pressure variation was changing with both bubbler heights and initial operating pressures. But the variation was had a same model with different bubbler heights at each initial operating pressures, whereas it was had a different model between different initial operating pressures. This model change due to, the interaction between velocity head and pressure head.

Subsequently the mean effective pressure (P_e) along the lateral pipe decreased with increasing bubbler distance from inlet. As a result the bubbler discharge (q) decreased for all bubbler tube heights (h_b) from 0 to 1.0 m at three initial operating pressures for the three bubbler tube diameters as shown in Table (A.1) in the appendix. This decreased in effective pressure (P_e) was a normal due to the friction losses along the lateral pipe.

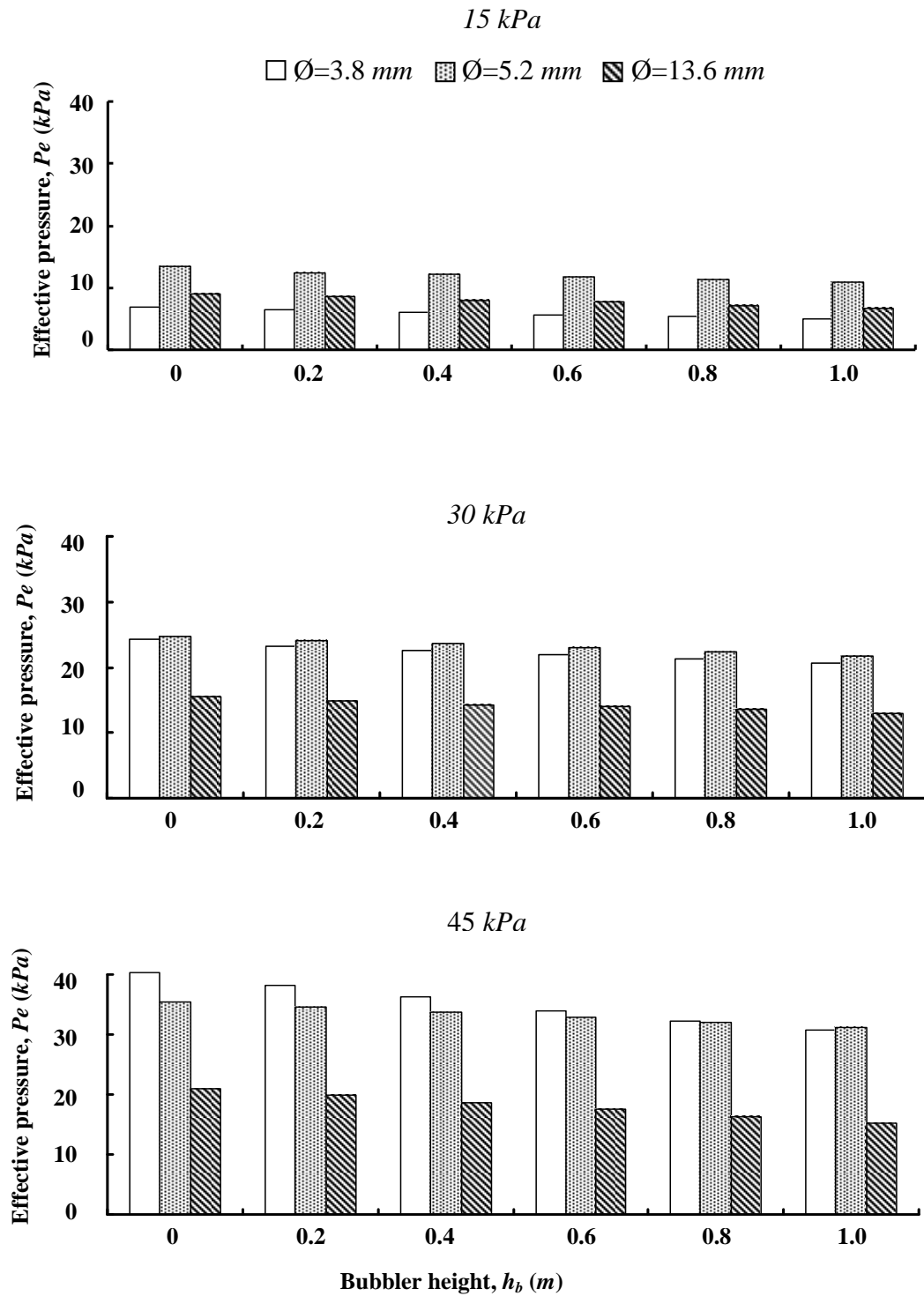


Figure (4.6): The relationship between bubbler height and effective pressure of different initial operating pressures and bubbler diameters (first case).

On the whole, for all bubbler tube diameters (ID), at all bubbler tube heights (h_b) from 0 to 1.0 m . The discharge uniformity (Cu) was relatively constant for the same initial operating pressure (P_i) for 3.8 mm bubbler diameter.

While for 5.2 mm bubbler diameter, the uniformity coefficient (Cu) was increased with initial operating pressure (P_i) increasing from 15 to 30 kPa and decreased with (P_i) increasing from 30 to 45 kPa .

But for ID , 13.6 mm bubbler diameter, the discharge uniformity coefficient (Cu) was decreased with initial operating pressure (P_i) increasing from 15 to 45 kPa as shown in Figure (4.5). The highest values of discharge uniformity (Cu) was recorded with bubbler diameter 5.2 and 3.8 mm , while (Cu) value was considered a marginal for 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.

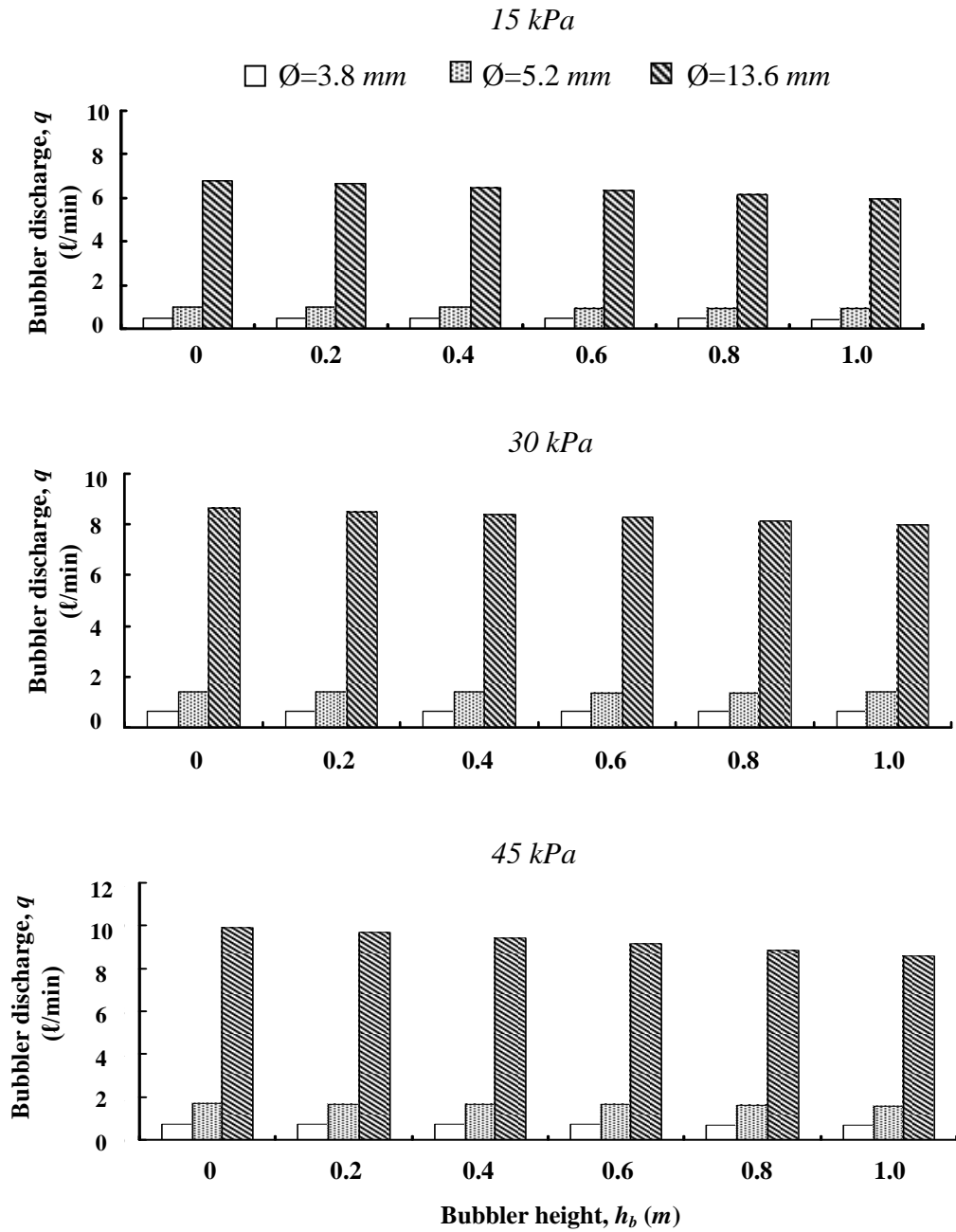


Figure (4.7): The relationship between bubbler height and bubbler discharge of different initial operating pressures and bubbler diameters (first case).

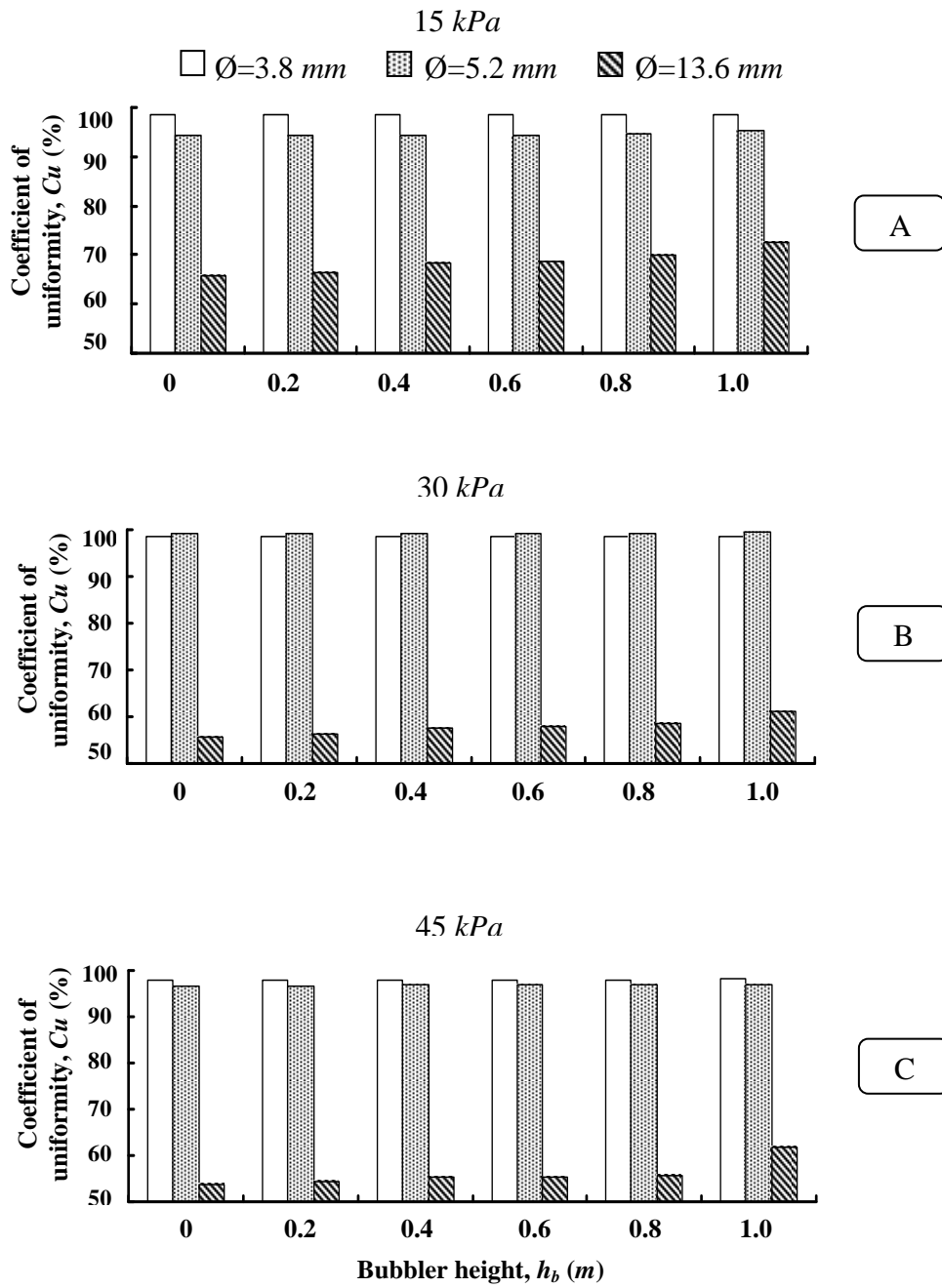


Figure (4.8): The relationship between bubbler height and coefficient of uniformity of different initial operating pressures and bubbler diameters (first case).

Initial operating pressure (15 kPa)

The discharge uniformity coefficient (C_u) for 3.8 mm bubbler diameter (ID) was high and constant 98.8% at all bubbler tube heights (h_b). On the other hand at (ID) 5.2 mm, the discharge uniformity (C_u) was relatively constant values $94.5 \pm 0.1\%$ with (h_b) increased from 0.0 to 0.6 m, and slightly increased from 94.8 to 95.6% with (h_b) increased from 0.8 to 1.0 m. but at (ID) 13.6 mm the discharge uniformity (C_u) was relatively constant values $66 \pm 0.2\%$ with (h_b) 0.0 and 0.2 m, and (C_u) increased from 66.8 to 72.8% with (h_b) increased from 0.4 to 1.0 m as shown in Figure (4.8.A).

In conclusion, the discharge uniformity was more sensitive to increasing bubbler height with (ID) 13.6 mm than 5.2 mm, and generally for the two previous diameters, the uniformity was increased with bubbler height increased from 0.4 to 1.0 m.

Initial operating pressure (30 kPa)

The discharge uniformity coefficient (C_u) for 3.8 mm bubbler diameter (ID) was high and constant 98.8% at all bubbler tube heights (h_b). On the other hand at (ID) 5.2 mm, the discharge uniformity (C_u) was constant values 99.2% with (h_b) 0.0 to 0.6 m, and slightly increased to 99.4% with increased from (h_b) 0.8 to 1.0 m. but at (ID) 13.6 mm the discharge uniformity (C_u) was relatively constant values $56 \pm 0.4\%$ with (h_b) 0.0 and 0.2 m, and (C_u) increased from 57.6 to 62.2% with (h_b) increased from 0.4 to 1.0 m.

To summaries, the discharge uniformity was more sensitive to increasing bubbler height with (ID) 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 (4.8.B).

Initial operating pressure (45 kPa)

The discharge uniformity coefficient (*Cu*) for 3.8 *mm* bubbler diameter (*ID*) was relatively constant $98.1 \pm 0.1\%$ at bubbler tube heights (*h_b*) 0.0 to 0.6 *m*, and slightly increased to 98.4% with (*h_b*) 0.8 to 1.0 *m*. On the other hand at (*ID*) 5.2 *mm*, the discharge uniformity (*Cu*) was constant value 96.8% with (*h_b*) 0.0 to 0.8 *m*, and slightly increased to 97% with (*h_b*) 1.0 *m*. but at (*ID*) 13.6 *mm* the discharge uniformity (*Cu*) was relatively constant values $54.3 \pm 0.1\%$ with (*h_b*) 0.0 and 0.2 *m*, and (*Cu*) increased from 55.4 to 61.8% with (*h_b*) increased from 0.4 to 1.0 *m*.

In conclusion, the discharge uniformity was more sensitive to increasing bubbler height with (*ID*) 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 (4.8.C).

Generally, it was inverse relationship between discharge and uniformity. As a result, the discharge uniformity increased with bubbler heights increasing, due to discharge (*q*) decreased Figure (4.8). These results have a good agreement with (El-meseery, 1993).

The results indicated that the highest value of discharge uniformity was obtained at initial operating pressure 30 *kPa* and 5.2 *mm* bubbler tube diameter for all tested ranges of bubblers tube diameters and initial operating pressures.

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

In this experiment, the effective pressure (P_e) corresponding to the highest discharge uniformity coefficient obtained with bubbler outlets (h_b) at the same level, was selected to apply it with (h_b) parallel to the hydraulic gradient line. Then (P_e) values above and below the selected one were tested to reach the highest uniformity.

The relationship between bubbler tube diameter (\emptyset), Initial operating pressure (P_i), effective pressure (P_e), bubbler discharge (q) and coefficient of uniformity (Cu); displayed in Table (4.4) and (A.2) in the appendix.

i.) Bubbler tube diameter (3.8 mm)

First, for initial operating pressure (P_i) 15 kPa, the discharge (q) values were 0.5, 0.51 and 0.52 l/min and the uniformity (Cu) values were 99.8, 99.2 and 98.6%, with mean effective pressure (P_e) 6, 7 and 8 kPa, respectively as shown in Figures (4.9.A) and (4.10.A). The relative discharge and uniformity difference calculated by equations (3.2) and (3.3) was -1.96 and 1.96%, 0.6 and -0.6%, respectively as shown in Figures (4.11) and (4.12).

Second, for (P_i) 30 kPa, the mean effective pressure (P_e) values were 26, 27 and 28 kPa. The discharge (q) values were 0.69, 0.7 and 0.71 l/min and the discharge uniformity (Cu) values were 99.4, 99.2 and 98.7%, respectively as shown in Figures (4.9.B) and (4.10.B). The relative discharge and uniformity difference was -2.85 and 1.4%, 0.2 and -0.5%, respectively as shown in Figures (4.11) and (4.12).

Table (4.4): Bubbler hydraulic properties of different locations and internal bubbler diameters of the same effective pressure (second case).

\emptyset <i>ID</i> <i>mm</i>	P_i <i>kPa</i>	P_e <i>kPa</i>	Mean discharge ℓ/min	Cu	Relative discharge difference	Relative uniformity difference
3.8	15	6	0.50	99.8	-1.96	0.60
		7	0.51	99.2	0.00	0.00
		8	0.52	98.6	1.96	-0.60
	30	26	0.69	99.4	-2.85	0.20
		27	0.70	99.2	0.00	0.00
		28	0.71	98.7	1.40	-0.50
	45	38	0.74	99.2	-2.60	0.20
		39	0.75	99.0	0.00	0.00
		40	0.76	98.5	2.60	-0.40
5.2	15	10	0.91	99.2	-3.00	0.40
		11	0.95	98.8	0.00	0.00
		12	1.00	98.6	3.00	-0.20
	30	27	1.49	99.6	-1.97	0.30
		28	1.52	99.3	0.00	0.00
		29	1.55	98.7	1.97	-0.60
	45	30	1.58	99.1	-1.90	0.20
		31	1.60	98.9	0.00	0.00
		32	1.63	98.6	1.90	-0.30
13.6	15	7	6.06	95.4	-5.70	0.84
		8	6.44	94.6	0.00	0.00
		9	6.79	92.8	5.60	-1.90
	30	12	7.73	84.6	-3.40	2.17
		13	8.00	82.8	0.00	0.00
		14	8.30	80.2	3.75	-3.14
	45	22	10.20	62.4	-1.40	4.70
		23	10.35	59.6	0.00	0.00
		24	10.56	56.3	1.90	-5.50

Third, for (P_i) 45 kPa, the discharge (q) values were 0.74, 0.75 and 0.76 ℓ/min , and the discharge uniformity (C_u) values were 99.2, 99.0 and 98.5%, with mean effective pressure (P_e) values 38, 39 and 40 kPa, as shown in Figures (4.9.C) and (4.10.C). The relative discharge and uniformity difference was -2.6% and 2.6%, 0.2% and -0.4%, respectively as shown in Figures (4.11) and (4.12).

ii.) *Bubbler tube diameter (5.2 mm)*

First, for (P_i) 15 kPa, the mean effective pressure (P_e) was 10, 11 and 12 kPa. The discharge (q) values were 0.91, 0.95 and 1.0 ℓ/min and the discharge uniformity (C_u) values were 99.2, 98.8 and 98.6%, respectively as shown in Figures (4.9.A) and (4.10.A). The relative discharge and uniformity difference was -3.0% and 3.0%, 0.4% and -0.2%, respectively as shown in Figures (4.11) and (4.12).

Second, for (P_i) 30 kPa, the discharge (q) values were 1.49, 1.52 and 1.55 ℓ/min and the discharge uniformity (C_u) values were 99.6, 99.3 and 98.7% with mean effective pressure (P_e) values were 27, 28 and 29 kPa, respectively as shown in Figures (4.9.B) and (4.10.B). The relative discharge and uniformity difference was -1.97% and 1.97%, 0.3% and -0.6%, respectively as shown in Figures (4.11) and (4.12).

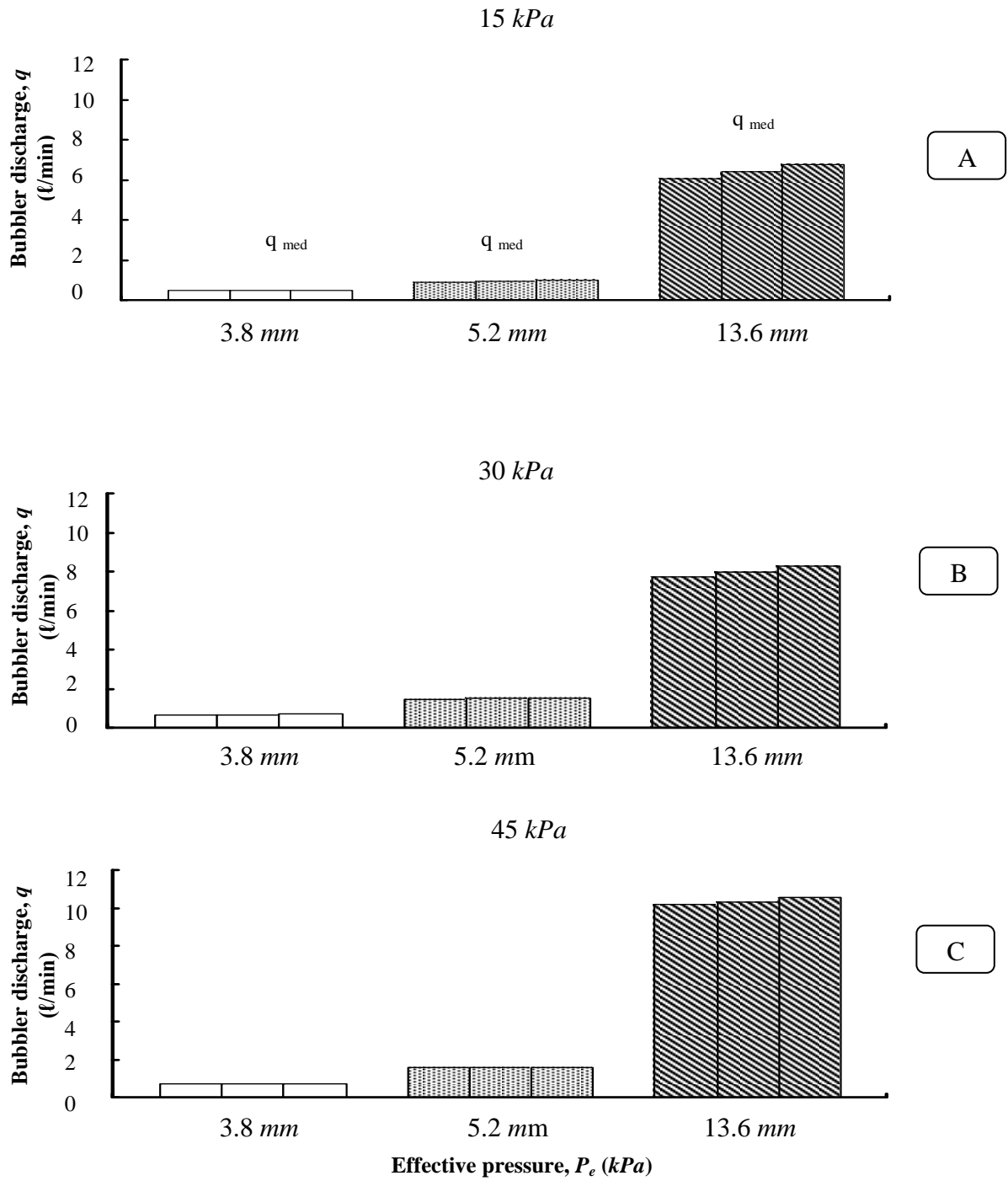


Figure (4.9): The relationship between effective pressure and bubbler discharge at the same initial operating pressures with different bubbler diameters (second case).

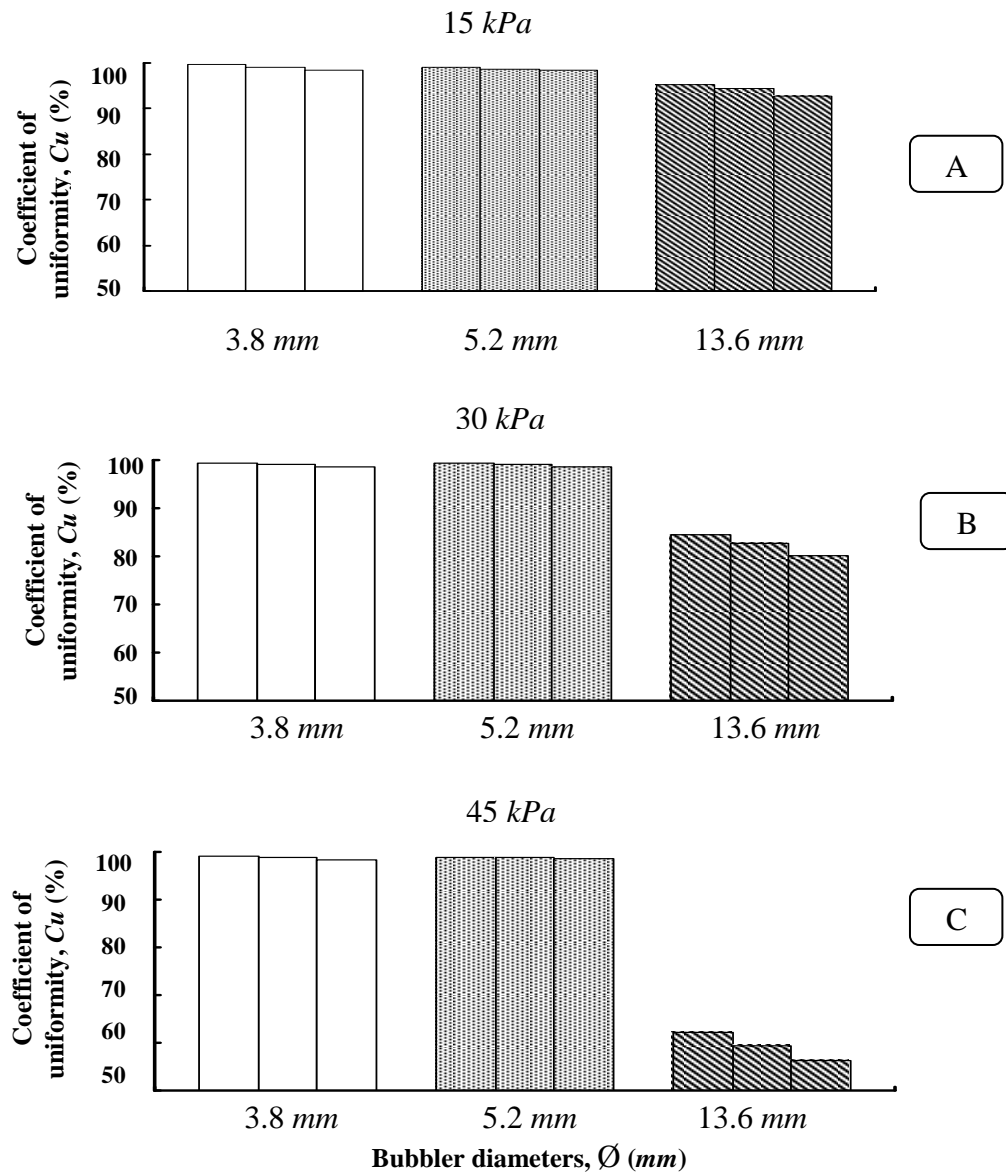


Figure (4.10): The relationship between bubbler diameter and coefficient of uniformity at the same initial operating pressures (second case).

Third, for (P_i) 45 kPa, the mean effective pressure (P_e) values were 30, 31 and 32 kPa. The discharge (q) values were 1.58, 1.6 and 1.63 l/min and the discharge uniformity (C_u) values were 99.1, 98.9 and 98.6%, respectively as shown in Figures (4.9.C) and (4.10.C). The relative discharge and uniformity difference was -1.9% and 1.9%, 0.2% and -0.3%, respectively as shown in Figures (4.11) and (4.12).

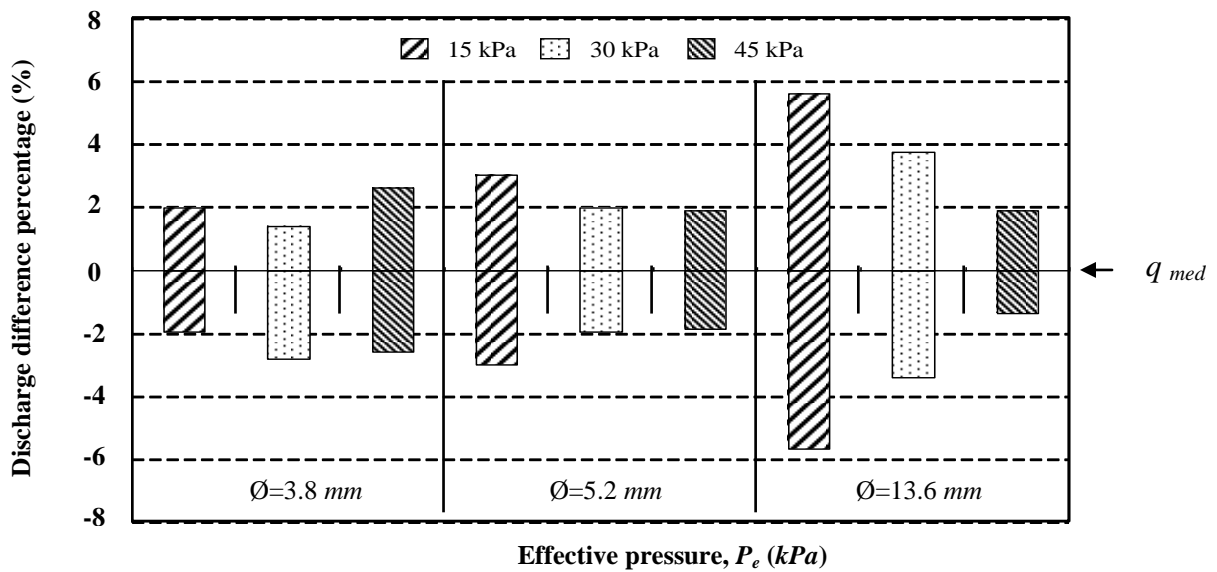


Figure (4.11): Discharge differences percentage (second case).

iii.) Bubbler tube diameter (13.6 mm)

First, for (P_i) 15 kPa, the mean effective pressures (P_e) were 7, 8 and 9 kPa. The discharge (q) values were 6.06, 6.44 and 6.79 l/min and the discharge uniformity (C_u) values were 95.4, 94.6 and 92.8%, respectively as shown in Figures (4.9.A) and (4.10.A). The relative discharge and uniformity difference was -5.7% and 5.6%, 0.84% and -1.9%, respectively as shown in Figures (4.11) and (4.12).

Second, for (P_i) 30 kPa, the mean effective pressure (P_e) values were 12, 13 and 14 kPa. The discharge (q) values were 7.73, 8 and 8.3 l/min and the discharge uniformity (C_u) values were 84.6, 82.8 and

80.2%, respectively as shown in Figures (4.9.B) and (4.10.B). The relative discharge and uniformity difference was -3.4% and 3.75%, 2.17% and -3.14%, respectively as shown in Figures (4.11) and (4.12).

Third, for (P_i) 45 kPa, the discharge (q) values were 10.2, 10.35 and 10.56 ℓ/min and the discharge uniformity (C_u) values were 62.4, 59.6 and 56.3%, with mean effective pressure (P_e) values were 22, 23 and 24 kPa, respectively as shown in Figures (4.9.C) and (4.10.C). The relative discharge and uniformity difference was -1.4% and 1.9%, 4.7% and -5.5%, respectively as shown in Figures (4.11) and (4.12).

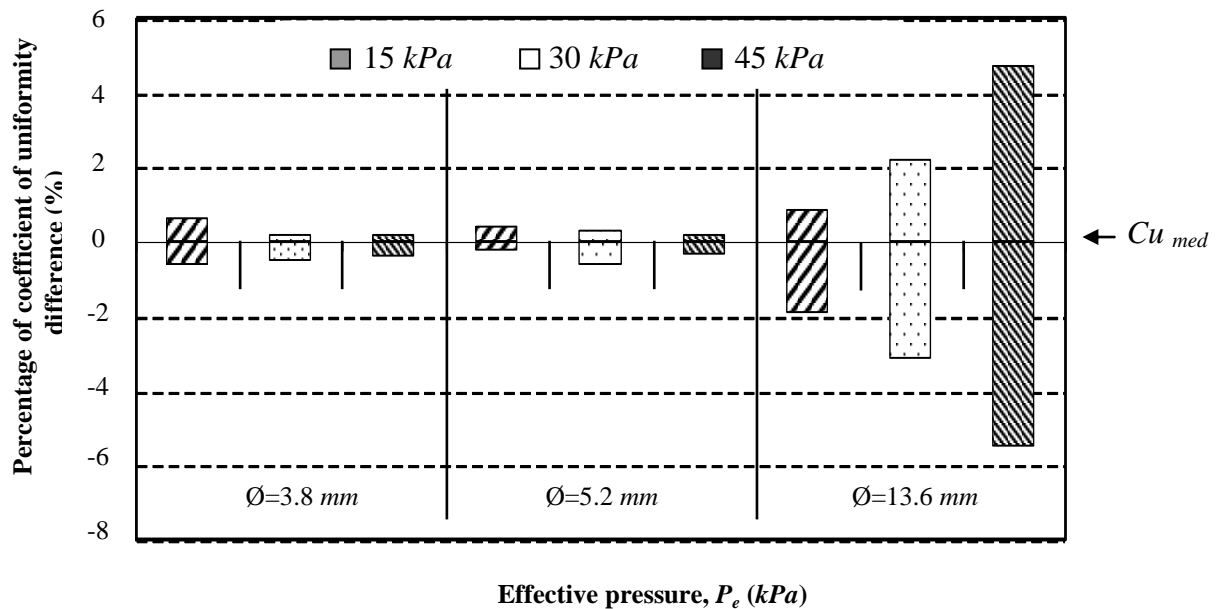


Figure (4.12): Uniformity coefficient differences percentage (second case).

It can be noticed that it is proportionally same bubbler discharges along the lateral pipe in case of bubbler outlets were parallel to the hydraulic gradient line as shown in Table (A.2) in the appendix.

In general we can say that it's inverse relationship between discharge uniformity and effective pressures for all bubbler tube diameters and initial operating pressure. It is clear that the discharge uniformity was very high in case of bubbler outlets were parallel to the hydraulic gradient line compared to bubbler outlets were at the same height. These results are agreement with **(Rawlins, 1977; Behoteguy & Thornton, 1980; Hull, 1981 and El-meseery, 1993)**.

In conclusion, the bubbler tube diameter (*ID*) 13.6 *mm* had the highest percentage of difference for uniformity and discharge compared to (*ID*) 3.8 and 5.2 *mm* as shown in Figures (4.11) and (4.12). In conclusion, this study is not recommended to use bubbler diameter (*ID*) 13.6 *mm* in low head bubbler irrigation systems.

Bubbler tube diameters 3.8 and 5.2 *mm*, there were no significant changes in (*Cu*) between initial operating pressures from 15 to 45 *kPa*. As shown in Figure (4.13 A, B). On the other hand, bubbler diameter 13.6 *mm* discharge uniformity was decreased with initial operating pressure increasing from 15 to 45 *kPa* as shown in Figure (4.13 C). These results agree with **(Ngigi, 2008)**.

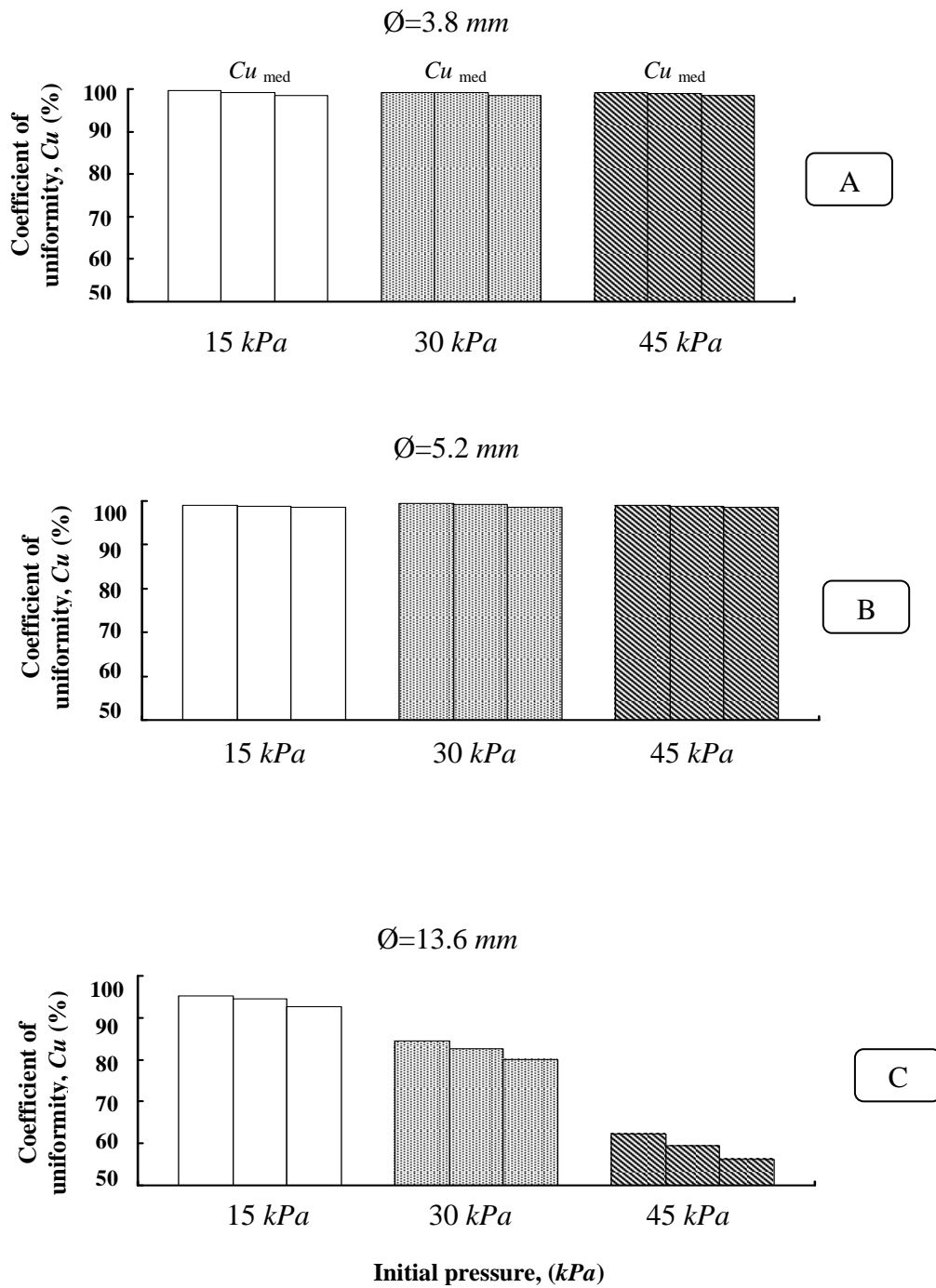


Figure (4.13): The relationship between initial operating pressure and coefficient of uniformity at the same bubbler diameter (second case).

4.2.2. Bubbler tube height

4.2.2.a. Theoretical bubbler tube height

Due to importance of calculation of bubbler height to get high values of coefficient of uniformity. The elevations of each bubbler tubes were calculated by equation to get the same flow of each bubbler tube along the lateral pipe, which that the aim of each bubbler irrigation system.

4.2.2.b. Theoretical bubbler height equation validation

The relationship between experimentally determination bubbler height (h_{bx}) and calculated bubbler height (h_{bc}) can be displayed in Table (4.5) and (A.3) in the appendix. The results explain that the bubbler height decreases with the bubbler distance (l_i) downstream.

By using variance analysis T -test, to show statistically different between the means of two groups, experimental and calculated bubbler height from each other and comparable calculated T with Table T .

i.) Bubbler tube diameter (3.8 mm)

First, for initial operating pressure (P_i) 15 kPa , the mean experimental bubbler height (h_{bx}) values were 0.38, 0.34 and 0.29 m , and the calculated bubbler height (h_{bc}) values were 0.39, 0.35 and 0.30 m , with mean bubbler discharge (q) 0.50, 0.51 and 0.52 ℓ/min , respectively as shown in Table (4.5). The calculated (T) value between experimental and calculated bubbler height was 0.2, 0.1 and 0.1, respectively.

Second, for (P_i) 30 kPa , the mean experimental bubbler height (h_{bx}) values were 0.99, 0.93 and 0.9 m , and the calculated bubbler height (h_{bc}) values were 1.0, 0.94 and 0.91 m , with mean bubbler discharge (q)

0.69, 0.70 and 0.71 ℓ/min , respectively as shown in Table (4.5). The calculated (T) value between experimental and calculated bubbler height was 0.68, 0.66 and 0.66, respectively.

Third, for (P_i) 45 kPa , the mean experimental height (h_{bx}) values were 0.87, 0.74 and 0.67 m , and the calculated bubbler height (h_{bc}) values were 0.88, 0.75 and 0.68 m , with mean bubbler discharge (q) 0.74, 0.75 and 0.76 ℓ/min , respectively as shown in Table (4.5). The calculated (T) value between experimental and calculated bubbler height was 0.86, 0.86 and 0.85, respectively.

ii.) Bubbler tube diameter (5.2 mm)

First, for initial operating pressure (P_i) 15 kPa , the mean experimental bubbler height (h_{bx}) values were 0.38, 0.30 and 0.19 m , and the calculated bubbler height (h_{bc}) values were 0.39, 0.31 and 0.20 m , with mean bubbler discharge (q) 0.91, 0.95 and 1.0 ℓ/min , respectively as shown in Table (4.5). The calculated (T) value between experimental and calculated bubbler height was 0.65, 0.64 and 0.64, respectively.

Second, for (P_i) 30 kPa , the mean experimental bubbler height (h_{bx}) values were 0.26, 0.23 and 0.23 m , and the calculated bubbler height (h_{bc}) values were 0.27, 0.24 and 0.24 m , with mean bubbler discharge (q) 1.49, 1.52 and 1.55 ℓ/min , respectively as shown in Table (4.5). The calculated (T) value between experimental and calculated bubbler height was 0.91, 0.91 and 0.90, respectively.

Table (4.5): Mean theoretical, experiment bubbler height for different bubbler diameters and initial operating pressure (second case).

\emptyset <i>ID</i> <i>mm</i>	P_i <i>kPa</i>	Discharge <i>q</i> ℓ/min	Bubbler height, h_b (cm)			
			Experimental	Calculated	<i>T</i> -value	<i>T</i> - table
3.8	15	0.50	0.38	0.39	0.20	2.3- 3.4
		0.51	0.34	0.35	0.10	2.3- 3.4
		0.52	0.29	0.30	0.10	2.3- 3.4
	30	0.69	0.99	1.00	0.68	2.3- 3.4
		0.70	0.93	0.94	0.66	2.3- 3.4
		0.71	0.90	0.91	0.66	2.3- 3.4
	45	0.74	0.87	0.88	0.86	2.3- 3.4
		0.75	0.74	0.75	0.86	2.3- 3.4
		0.76	0.67	0.68	0.85	2.3- 3.4
5.2	15	0.91	0.38	0.39	0.65	2.3- 3.4
		0.95	0.30	0.31	0.64	2.3- 3.4
		1.00	0.19	0.20	0.64	2.3- 3.4
	30	1.49	0.26	0.27	0.91	2.3- 3.4
		1.52	0.23	0.24	0.91	2.3- 3.4
		1.55	0.23	0.24	0.90	2.3- 3.4
	45	1.58	0.97	0.98	0.95	2.3- 3.4
		1.60	0.89	0.90	0.95	2.3- 3.4
		1.63	0.79	0.80	0.95	2.3- 3.4
13.6	15	6.06	0.70	0.71	0.92	2.3- 3.4
		6.44	0.67	0.68	0.91	2.3- 3.4
		6.79	0.65	0.66	0.91	2.3- 3.4
	30	7.73	1.13	1.14	0.98	2.3- 3.4
		8.00	1.10	1.11	0.97	2.3- 3.4
		8.30	1.05	1.06	0.97	2.3- 3.4
	45	10.20	0.74	0.75	0.98	2.3- 3.4
		10.35	0.70	0.71	0.98	2.3- 3.4
		10.56	0.64	0.65	0.98	2.3- 3.4

Third, for (P_i) 45 kPa, the mean experimental height (h_{bx}) values were 0.97, 0.89 and 0.79 m, and the calculated bubbler height (h_{bc}) values were 0.98, 0.90 and 0.80 m, with mean bubbler discharge (q) 1.58, 1.6 and 1.63 ℓ/min , respectively as shown in Table (4.5). The calculated (T) value between experimental and calculated bubbler height was 0.95, 0.95 and 0.95, respectively.

iii.) *Bubbler tube diameter (13.6 mm)*

First, for initial operating pressure (P_i) 15 kPa, the mean experimental bubbler height (h_{bx}) values were 0.70, 0.67 and 0.65 m, and the calculated bubbler height (h_{bc}) values were 0.71, 0.68 and 0.66 m, with mean bubbler discharge (q) 6.06, 6.44 and 6.79 ℓ/min , respectively as shown in Table (4.5). The calculated (T) value between experimental and calculated bubbler height was 0.92, 0.91 and 0.91, respectively.

Second, for (P_i) 30 kPa, the mean experimental bubbler height (h_{bx}) values were 1.13, 1.10 and 1.05 m, and the calculated bubbler height (h_{bc}) values were 1.14, 1.11 and 1.06 m, with mean bubbler discharge (q) 7.73, 8.0 and 8.30 ℓ/min , respectively as shown in Table (4.5). The calculated (T) value between experimental and calculated bubbler height was 0.98, 0.97 and 0.97, respectively.

Third, for (P_i) 45 kPa, the mean experimental height (h_{bx}) values were 0.74, 0.70 and 0.64 m, and the calculated bubbler height (h_{bc}) values were 0.75, 0.71 and 0.65 m, with mean bubbler discharge (q) 10.2, 10.35 and 10.56 ℓ/min , respectively as shown in Table (4.5). The calculated (T) value between experimental and calculated bubbler height was 0.98, 0.98 and 0.98, respectively.

Finally, it was found that the bubbler height decreased along the lateral line as shown in Table (4.5) and (A.3) in the appendix.

Because T Table was greater than T calculated, the hypothesis theory is accepted. Therefore equation (4.4) is very suitable for estimating bubbler height along lateral line.

The relationship between calculated and experimental bubbler heights can be presented in Figure (4.14). It is noticed that the relation between calculated and experimental bubbler heights is linear making 45° and also good correlation was observed.

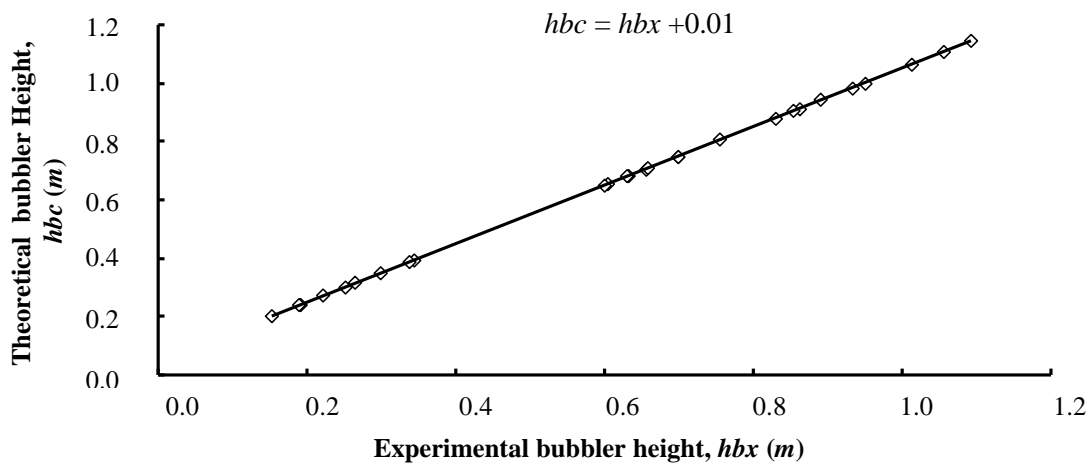


Figure (4.14): The relationship between theoretical and experimental bubbler height.

The equation after adjustment to disappear difference between calculated and experimental bubbler height as follows:

$$hbn = \left(H_i - \left(\frac{q}{k} \right)^{\left(\frac{1}{x} \right)} - \left(61111 \times q^{1.75} \times D^{-4.75} (s + cl) \sum_{n=1}^N (N - n + 1)^{1.75} \right) \right) - 1 \dots \dots \dots (4.1)$$

5. SUMMARY AND CONCLUSIONS

There is a great need to apply modern irrigation systems to reduce water losses and energy consumption under Egyptian conditions. Bubbler irrigation systems are rarely used under Egyptian conditions because farmers Lack of awareness of its importance.

Low-head bubbler systems differ from other micro-irrigation systems because they are based on gravity-flow, can operate at pressure head as low as 1 m (3.3 ft) and do not require elaborate filtration systems. The experimental work was carried out at the research Farm, Faculty of Agriculture, Suez Canal University. It is aimed to evaluate the performance of three bubbler tube diameters (\emptyset) and different initial operating pressures (P_i) on discharge uniformity coefficient (C_u) in two different cases, first: Bubbler outlets at equal elevation and second: Bubbler outlets were parallel to the hydraulic gradient line. Also determine the optimum bubbler height (h_b) of each bubbler tube diameter to achieve high discharge uniformity when bubbler outlets were parallel to the hydraulic gradient line. Studied variables in this research were operating pressures 15, 30 and 45 *kPa*, bubblers diameters 3.8, 5.2 and 13.6 *mm* with Permutations and combinations of six bubbler heights (0.0, 0.2, 0.4, 0.6, 0.8 and 1.0 *m*) were investigated in first case, and combinations of three effective pressures (P_e) in second case. The following criteria were taken into consideration: Bubbler discharge, effective pressure and discharge uniformity coefficient.

The obtained results have been led to the following recommended points.

1- The mean effective pressure (P_e) and the mean discharge (q) were proportionally increased with initial operating pressure (P_i) increasing for all bubbler tube heights and diameters.

2- The mean effective pressure (P_e) 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.

3- The mean effective pressure (P_e) along the lateral pipe decreased with increasing bubbler distance from inlet.

4- In the first 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 .

- 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 operating pressure from 15 to 45 kPa ,
- 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 ,
- 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 .

5-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 pressures increasing from 15 to 45 kPa compared with the ID 13.6 mm bubbler tube diameter.

6- 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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Table (1): Bubbler effective pressure (P_e), discharge (q) and uniformity (Cu) along the lateral pipe at different initial operating pressures (P_i) for internal bubbler diameters (\emptyset) at the same bubbler heights (h_b) (first case) versus effective pressure.

h_b m	\emptyset ID mm	P_i kPa	Bubbler discharge (ℓ / min)										Cu $\%$
			Bubbler number										
			1		2		3		4		5		
			P_e	q	P_e	q	P_e	q	P_e	q	P_e	q	
0	3.8	15	8.2	0.53	7.8	0.52	6.9	0.51	6.3	0.50	5.9	0.49	98.8
		30	27.2	0.70	25.9	0.69	24.6	0.68	23.1	0.67	21.1	0.66	98.8
		45	44.7	0.78	44.2	0.78	42.2	0.77	37.7	0.75	33.5	0.73	98.2
	5.2	15	14.8	1.11	14.1	1.08	13.3	1.05	12.8	1.03	9.8	0.90	94.4
		30	25.1	1.44	25.1	1.44	24.9	1.43	24.7	1.43	24.3	1.42	99.2
		45	37.4	1.77	36.5	1.74	35.8	1.73	34.5	1.69	33.7	1.67	96.8
	13.6	15	10.9	7.42	9.9	7.1	8.7	6.69	8.2	6.53	7.9	6.41	65.8
		30	17.8	9.22	17.3	9.1	16.5	8.89	14.5	8.39	12.5	7.90	56
		45	25.9	10.9	21.8	10.1	20.4	9.84	19.6	9.65	17.5	9.15	54.2
0.2	3.8	15	7.6	0.52	7.2	0.51	6.4	0.50	5.90	0.49	5.4	0.48	98.8
		30	26.1	0.69	25.0	0.69	23.5	0.68	22.1	0.67	20.3	0.65	98.8
		45	43.0	0.78	41.4	0.77	39.8	0.76	35.6	0.74	31.7	0.72	98
	5.2	15	13.8	1.07	12.9	1.04	12.5	1.02	12.1	0.97	9.3	0.88	94.4
		30	24.7	1.43	24.5	1.42	24.2	1.41	23.9	1.41	23.6	1.41	99.2
		45	37.0	1.75	35.7	1.72	34.6	1.70	33.6	1.67	32.4	1.64	96.8
	13.6	15	10.5	7.28	9.3	6.89	8.2	6.53	7.7	6.35	7.5	6.26	66.2
		30	16.9	9.03	16.4	8.9	15.7	8.74	13.7	8.20	12.3	7.78	56.8
		45	24.4	10.6	20.7	9.88	19.2	9.56	18.3	9.36	16.9	9.01	54.4
0.4	3.8	15	7.2	0.51	6.9	0.51	6.1	0.49	5.5	0.48	5.1	0.48	98.8
		30	25.6	0.69	24.2	0.68	22.8	0.67	21.4	0.66	19.8	0.65	98.8
		45	41.0	0.77	39.9	0.76	37.4	0.75	33.6	0.73	29.8	0.71	98.2
	5.2	15	13.6	1.06	12.8	1.03	12.3	1.01	11.8	0.99	8.7	0.85	94.6
		30	24.3	1.42	23.9	1.41	23.7	1.40	23.5	1.40	23.1	1.39	99.2
		45	36.5	1.74	34.5	1.69	33.5	1.67	32.9	1.66	31.9	1.63	96.8
	13.6	15	10.2	7.18	8.5	6.61	7.6	6.29	7.3	6.20	7.1	6.12	66.8
		30	16.4	8.89	15.8	8.76	15.2	8.63	13.0	8.06	11.7	7.69	57.6
		45	23.0	10.4	19.5	9.63	18.5	9.34	17.3	9.12	15.0	8.72	55.4

Continue Table (A. 1):

h_b <i>m</i>	\varnothing <i>ID</i> <i>mm</i>	P_i <i>kPa</i>	Bubbler discharge (ℓ /min)										<i>Cu</i> %
			Bubbler number										
			1		2		3		4		5		
			P_e	q	P_e	q	P_e	q	P_e	q	P_e	q	
0.6	3.8	15	6.7	0.51	6.4	0.5	5.7	0.49	5.3	0.48	4.8	0.47	98.8
		30	25	0.69	23.3	0.68	22	0.67	20.7	0.66	19.3	0.65	98.8
		45	39	0.76	37.7	0.75	34.7	0.74	31	0.72	28.1	0.7	98
	5.2	15	13	1.04	12.3	1.01	11.8	0.99	11.6	0.98	8.5	0.84	94.6
		30	23.5	1.39	23.3	1.39	23.1	1.38	22.8	1.37	22.4	1.37	99.2
		45	35.5	1.72	33.5	1.67	32.9	1.65	32.2	1.63	31.2	1.61	96.8
	13.6	15	9.6	7.01	8.1	6.47	7.3	6.19	7	6.08	6.8	5.98	68.4
		30	15.6	8.76	15.6	8.68	14.8	8.5	12.7	7.92	11.6	7.62	58
		45	21.7	10.1	18.3	9.35	17.1	9.06	15.9	8.78	15	8.55	55.4
0.8	3.8	15	6.5	0.5	6	0.49	5.4	0.48	5.1	0.47	4.5	0.46	98.8
		30	24.3	0.68	22.6	0.67	21.1	0.66	19.8	0.65	18.7	0.64	98.8
		45	37	0.75	35.6	0.74	32.3	0.73	29.5	0.71	27.9	0.7	98.4
	5.2	15	12.6	1.02	11.8	0.99	11.3	0.97	11.1	0.96	8.3	0.83	94.8
		30	23.1	1.38	22.8	1.38	22.6	1.37	22.2	1.36	21.9	1.35	99.4
		45	35	1.7	32.7	1.65	31.7	1.63	31.2	1.61	30.4	1.59	96.8
	13.6	15	9	6.82	7.5	6.27	6.7	5.96	6.6	5.93	6.4	5.84	69.6
		30	15.3	8.61	15.1	8.56	14.2	8.37	12.4	7.8	11.4	7.5	58.6
		45	20	9.75	17.1	9.06	15.7	8.72	14.8	8.49	13.8	8.24	55.8
1.0	3.8	15	6	0.49	5.7	0.49	5.1	0.47	4.8	0.47	4.2	0.45	98.8
		30	23.4	0.68	22.1	0.67	20.6	0.66	19.4	0.65	18.2	0.64	98.8
		45	35	0.74	33.5	0.73	31.7	0.72	28.1	0.7	26.3	0.69	98.4
	5.2	15	12	1	11.3	0.97	10.8	0.95	10.6	0.94	8.1	0.82	95.6
		30	22.2	1.35	22.1	1.35	21.9	1.34	21.7	1.34	21.1	1.33	99.4
		45	34	1.68	31.7	1.62	30.8	1.6	29.9	1.58	29.5	1.57	97
	13.6	15	8.5	6.63	6.9	6.05	6.5	5.83	6.2	5.78	6.1	5.71	72.8
		30	14.7	8.44	14.2	8.37	13.7	8.19	11.9	7.68	10.9	7.41	62.2
		45	19	9.4	15.9	8.78	14.8	8.48	14.2	8.34	13.1	8.06	61.8

Table (2): Bubbler hydraulic properties of different locations and internal bubbler diameters (\emptyset) of the same effective pressure (P_e) along the lateral pipe, (second case).

\emptyset <i>ID</i> <i>mm</i>	P_i <i>kPa</i>	P_e <i>kPa</i>	Bubbler discharge (ℓ/min)					Cu
			Bubbler number					
			1	2	3	4	5	
3.8	15	6	0.50	0.50	0.50	0.50	0.49	99.8
		7	0.52	0.51	0.51	0.50	0.49	99.2
		8	0.55	0.53	0.52	0.51	0.50	98.6
	30	26	0.69	0.68	0.68	0.67	0.67	99.4
		27	0.71	0.70	0.70	0.69	0.69	99.2
		28	0.73	0.72	0.71	0.70	0.69	98.7
	45	38	0.76	0.75	0.74	0.74	0.73	99.2
		39	0.77	0.76	0.75	0.74	0.74	99
		40	0.79	0.78	0.78	0.76	0.74	98.5
	5.2	15	10	0.93	0.92	0.91	0.91	0.90
11			0.97	0.96	0.95	0.94	0.93	98.8
12			1.02	1.02	1.00	0.99	0.98	98.6
30		27	1.50	1.49	1.49	1.49	1.48	99.6
		28	1.53	1.52	1.52	1.51	1.50	99.3
		29	1.59	1.56	1.55	1.54	1.53	98.7
45		30	1.59	1.59	1.58	1.57	1.56	99.1
		31	1.62	1.61	1.61	1.60	1.58	98.9
		32	1.64	1.64	1.63	1.62	1.60	98.6
13.6	15	7	6.14	6.10	6.04	6.03	6.00	95.4
		8	6.53	6.49	6.44	6.41	6.34	94.6
		9	6.95	6.88	6.80	6.77	6.72	92.8
	30	12	8.09	7.76	7.66	7.62	7.53	84.6
		13	8.37	8.05	7.90	7.90	7.76	82.8
		14	8.67	8.38	8.18	8.16	7.99	80.2
	45	22	10.9	10.35	10.12	9.90	9.50	62.4
		23	11.05	10.67	10.37	10.09	9.62	59.6
		24	11.39	10.82	10.43	10.10	10.05	56.3

Table (3): Theoretical (*hbc*) and experiment (*hbx*) bubbler height at different bubbler diameters (\varnothing) and initial operating pressures (*P_i*) along the lateral pipe, (second case).

ID mm	P _i kPa	Discharge , ℓ /min	Bubbler location " <i>l_i</i> ",(m)									
			6		12		18		24		30	
			Bubbler height " <i>h_b</i> ",(m)									
			Exp	cal	Exp	cal	Exp	cal	Exp	cal	Exp	cal
3.8	15	0.50	0.40	0.41	0.39	0.40	0.38	0.39	0.38	0.39	0.37	0.38
		0.51	0.35	0.36	0.34	0.35	0.34	0.35	0.33	0.34	0.33	0.34
		0.52	0.30	0.31	0.30	0.31	0.29	0.30	0.29	0.30	0.28	0.29
	30	0.69	1.04	1.05	1.01	1.02	0.99	1.00	0.96	0.97	0.95	0.96
		0.70	0.98	0.99	0.95	0.96	0.93	0.94	0.91	0.92	0.89	0.90
		0.71	0.95	0.96	0.92	0.93	0.90	0.91	0.88	0.89	0.86	0.87
	45	0.74	0.98	0.99	0.92	0.93	0.87	0.88	0.81	0.82	0.77	0.78
		0.75	0.85	0.86	0.79	0.80	0.73	0.74	0.68	0.69	0.64	0.65
		0.76	0.78	0.79	0.72	0.73	0.67	0.68	0.62	0.63	0.57	0.58
5.2	15	0.91	0.42	0.43	0.40	0.41	0.37	0.38	0.35	0.36	0.34	0.35
		0.95	0.35	0.36	0.32	0.33	0.30	0.31	0.28	0.29	0.27	0.28
		1.00	0.24	0.25	0.21	0.22	0.19	0.20	0.17	0.18	0.16	0.17
	30	1.49	0.44	0.45	0.34	0.35	0.25	0.26	0.17	0.18	0.11	0.12
		1.52	0.41	0.42	0.31	0.32	0.22	0.23	0.14	0.15	0.08	0.09
		1.55	0.40	0.41	0.30	0.31	0.22	0.23	0.14	0.15	0.08	0.09
	45	1.58	1.32	1.33	1.13	1.14	0.96	0.97	0.80	0.81	0.66	0.67
		1.60	1.24	1.25	1.05	1.06	0.88	0.89	0.72	0.73	0.58	0.59
		1.63	1.14	1.15	0.95	0.96	0.78	0.79	0.62	0.63	0.48	0.49
13.6	15	6.06	0.93	0.94	0.76	0.77	0.65	0.66	0.58	0.59	0.55	0.56
		6.44	0.89	0.90	0.73	0.74	0.62	0.63	0.57	0.58	0.54	0.55
		6.79	0.86	0.87	0.70	0.71	0.60	0.61	0.55	0.56	0.53	0.54
	30	7.73	1.69	1.70	1.31	1.32	1.04	1.05	0.86	0.87	0.76	0.77
		8.00	1.64	1.65	1.27	1.28	1.00	1.01	0.83	0.84	0.74	0.75
		8.30	1.58	1.59	1.21	1.22	0.96	0.97	0.80	0.81	0.71	0.72
	45	10.2	1.69	1.70	1.05	1.06	0.59	0.60	0.28	0.29	0.10	0.11
		10.4	1.64	1.65	1.00	1.01	0.54	0.55	0.24	0.25	0.07	0.08
		10.6	1.57	1.58	0.93	0.94	0.48	0.49	0.19	0.20	0.02	0.03

الملخص العربي

هناك حاجة ماسة للتوسع في تطبيق نظم الري الحديثة لتقليل الفاقد من المياه واستهلاك الطاقة في ظل الظروف المصرية. نادرا ما يتم استخدام نظام الري النافوري مع المزارعين المصريين بسبب عدم الوعي بأهميته.

يختلف نظام الري النافوري ذو الضاغط المنخفض عن باقي نظم الري الدقيق حيث انه يعتمد تشغيله علي استخدام ضواغط منخفضة تصل إلي 1 متر ولا يحتاج وحدة ترشيح دقيقة. ويهدف هذا البحث إلى دراسة تأثير ضغوط التشغيل المختلفة مع أقطار نافورات مختلفة على انتظامية توزيع المياه في حالتين: الأولى عند تساوي ارتفاع النافورات والثانية عند موازاة ارتفاع النافورات لخط الميل الهيدروليكي. وكذلك تحديد الارتفاع الأمثل للنافورات لكل قطر في حالة موازاة ارتفاع النافورات لخط الميل الهيدروليكي من أجل تحقيق اعلي انتظامية توزيع المياه. أجريت التجارب بمزرعة كلية الزراعة، جامعة قناة السويس بالإسماعيلية. أخذت المعايير التالية في الاعتبار عند التقييم:- معدل تصرف النافورة (q) والضغط الفعال (Pe) ومعامل انتظامية التوزيع (Cu)، تحت تأثير كل من:-

- 1- ضغوط تشغيل ابتدائية 15، 30، 45 ك باسكال.
- 2- أقطار نافورات داخلية 3.8، 5.2، 13.6 مم.

وتوصلت الدراسة إلى النتائج التالية:-

- 1- يزداد متوسط الضغط الفعال ومتوسط التصرف زيادة متناسبة مع زيادة ضغوط التشغيل لكل أقطار النافورات ومع كل الارتفاعات.
- 2- يقل متوسط الضغط الفعال نتيجة زيادة ارتفاع النافورة. وبالتالي يقل تصرف النافورة بالتتابع مع زيادة ارتفاع النافورات من 0.0، 0.2، 0.4، 0.6، 0.8 و 1.0 م مع الثلاث ضغوط التشغيل الابتدائية والثلاث أقطار النافورات.
- 3- يقل متوسط الضغط الفعال علي طول الخط الجانبي مع زيادة المسافة بين النافورات من بداية الخط.
- 4- في الحالة الأولى، هناك علاقة عكسية بين الانتظامية والتصرف. تم تسجيل أعلي قيم لانتظامية التوزيع (Cu) مع قطر نافورة 5.2 و 3.8 مم في حين كانت قيم الانتظامية منخفضة لقطر نافورة 13.6 مم.

- بالنسبة لقطر نافورة 3.8 مم, كانت قيم انتظامية التوزيع (Cu) مع كل ارتفاعات النافورات من 0.0 وحتى 1.0 متر تقريبا ثابتة وقيمتها بين (98.4 إلى 98.8%) مع ضغوط التشغيل من 15 إلى 45 ك باسكال.
- بالنسبة لقطر نافورة 5.2 مم, كانت قيم انتظامية التوزيع (Cu) تتقلب قليلا من (94.4 إلى 97%) مع زيادة ضغوط التشغيل من 15 إلى 45 ك باسكال.
- لكن مع قطر نافورة 13.6 مم, كانت قيم انتظامية التوزيع (Cu) تقل من (65.8 إلى 61.8%) مع زيادة ضغوط التشغيل من 15 إلى 45 ك باسكال وهي قيم غير مقبولة عمليا.

5- في الحالة الثانية, عند موازنة ارتفاع النافورات لخط الميل الهيدروليكي. تم الحصول علي نفس التصرفات من كل النافورات علي طول الخط الجانبي.

- من الواضح أن قيم انتظامية التوزيع (Cu) في الحالة الثانية كانت أعلى من قيم الانتظامية في الحالة الأولى, لكن لا توجد فروق معنوية في قيم الانتظامية مع قطري نافورتين 3.8 و 5.2 مم مع زياده ضغوط التشغيل من 15 إلى 45 ك باسكال مقارنة بقطر نافورة 13.6 مم.

6- بسبب عدم وجود اختلافات معنوية في قيم الانتظامية بين الحالة الأولى والثانية لتصميم نظام الري الفوار ذو الضاغط المنخفض, توصي الدراسة باستخدام التصميم البسيط وهو الحالة الأولى عن الحالة الثانية مع قطر نافورة 3.8 و 5.2 مم بالمقارنة مع قطر نافورة 13.6 مم.

أحمد عبد الكريم هاشم عبد النبي	اسم صاحب الرسالة
دراسات علي تصميم نظام ري فوار ذو ضاغط منخفض	عنوان الرسالة
قناة السويس	الجامعة
الزراعة	الكلية
الهندسة الزراعية	القسم العلمي المانح للرسالة
ماجستير في العلوم الزراعية (هندسة زراعية)	الدرجة العلمية
2011/9/14	تاريخ المنح
الإنجليزية	لغة الرسالة
أستاذ دكتور/ شريف محمد عبد الحق أستاذ دكتور/ محمود هاني رمضان دكتور/ محمد أبو زيد رشاد	أسماء لجنة الإشراف

الموجز العربي

<p>الهدف الأساسي لهذا البحث تقييم أداء ثلاث أقطار للنافورات تحت ثلاث ضغوط تشغيل ابتدائية 15، 30، 45 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:</p> <p>أولاً: مخرج النافورات في نفس المستوي عند ارتفاع النافورات 0.0، 0.2، 0.4، 0.6، 0.8 و 1.0م. وأظهرت النتائج أن أعلى قيم لمعامل انتظامية التوزيع (Cu) تم الحصول عليها لقطر نافورة 5.2 مم مع ضغط تشغيل 30 ك باسكال حيث كانت قيم الانتظامية تقريبا ثابتة بمتوسط 99.3%.</p> <p>ثانياً: مخرج النافورات موازي لخط الميل الهيدروليكي وذلك تحت تأثير ثلاث ضغوط فعالة لكل ضغط تشغيل ابتدائي حيث كان واضحاً انه يعطي نفس التصرف من جميع النافورات للقطر 3.8 و 5.2 مم ولكنه يعطي تصرفات مختلفة مع القطر 13.6 مم.</p> <p>و يوصى بتشغيل قطر نافورة 5.2 مم مع ضغط تشغيل ابتدائي 30 ك باسكال لتحقيق معامل انتظاميه عاليه بالإضافة لتحقيق خط جانبي أطول مقارنة عند استخدام نافورة بقطر 3.8 مم لتقليل تكلفة إنشاء النظام الأولية. أوضحت الدراسة أن قطر نافورة 13.6 مم غير موصي بها لنظام الري الفوار ذو الضاغط المنخفض نتيجة لقلة انتظامية توزيع المياه.</p>	
الكلمات الدالة:	الري النافوري - الري منخفض الضغط - معامل انتظامية التوزيع (Cu) - أداء الري النافوري.

لجنة الحكم والمناقشة

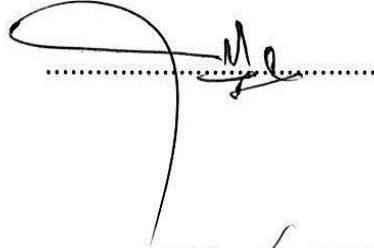
الإسم : أحمد عبد الكريم هاشم عبد النبي

عنوان الرسالة : دراسات علي تصميم نظام ري فوار ذو
ضاغط منخفض

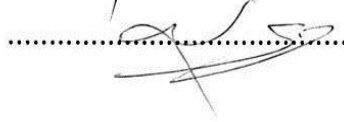
رسالة مقدمة

كجزء من المتطلبات التكميلية للحصول على درجة الماجستير في العلوم
الزراعية (الهندسة الزراعية)

لجنة الحكم والمناقشة



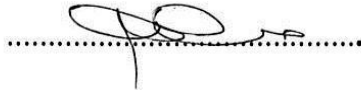
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التاريخ: ٢٠١١/٩/١٤ م

دراسات علي تصميم نظام ري فوار ذو ضاغط منخفض

رسالة مقدمة من

أحمد عبد الكريم هاشم عبد النبي

بكالوريوس في العلوم الزراعية - ميكنة زراعية - جامعة قناة السويس
٢٠٠٦

كجزء من المتطلبات التكميلية
للحصول على درجة الماجستير في العلوم الزراعية
(الهندسة الزراعية)

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جامعة قناة السويس

٢٠١١



جامعة قناة السويس
كلية الزراعة
قسم الهندسة الزراعية

دراسات علي تصميم نظام ري فوار ذو ضاغط منخفض

رسالة مقدمة من

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بكالوريوس في العلوم الزراعية - ميكنة زراعية - جامعة قناة السويس
2006

كجزء من المتطلبات التكميلية
للحصول على درجة الماجستير في العلوم الزراعية

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2011