ChemTech

International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.9, No.03 pp 127-139, 2016

Hydraulic Characteristics for Predicting Water Distribution of Self – Compensating Gated Pipe Irrigation Technique

Hussein M. M.[1], A.M. El-Gindy [2], H.M. Mehanna[1], A. F. EL-Shafie.[1]

[1]Water Relations & Field Irrigation Department, National Research Centre, Dokki, Giza, Egypt.
[2]Agricultural Engineering Dept., Fac., of Agriculture, Ain Shams University, Cairo, Egypt.

Corresponding author: El-Shafie A. F., ahmedfaris@yahoo.com

Abstract: Predicting water distribution and maximizing water efficiency became the priority of irrigation planners and users under Egyptian conditions. Therefore, the aim of this study the hydraulic performance analysis of self-compensating gated outlet (SCGO) 50 mm outlet diameter. As well as, field evaluation of modified (SCGO) gated pipe irrigation technique compared with traditional, for predicting water flow along Pipeline. It was carried out using two P.V.C pipe lines of 110 mm diameter and 50 mm outlet diameter, and three outlet gate spacings between gates (0.7, 1.0 and 1.5 m). Hereby field experiments were carried out at the Experimental Farm of Faculty of Agriculture, Ain Shams University, Kalubia Governorate, Egypt, which represents alluvial soils. Results revealed that. In laboratory experiments the discharge l s^{-1} was measured for (SCGO) under different operating pressure in the range (0.08-0.28 bar). The gate discharge under different operating pressure kept around 0.52 l s^{-1} for 50 mm, outlet diameter, with coefficients of variation less than 0.09%.. The discharge l s^{-1} was measured for traditional and modified gated pipe at different gate spacings of 0.7, 1.0 1.5 m between gates. In general, there was a slight variation in discharge between first and last gate for modified gated pipe under 0.7, 1.0 and 1.5 m outlet spacings. As the data indicated a slight discharge variation between all gates under 1.5 m spacing there was more discharge variation under 0.7, 1.0 m gate spacings for traditional gated pipe. The relationship between measured and predicted values of discharge along the pipeline for traditional and modified gated pipe under 0.7 , 1.0 and 1.5 m gate spacings, reflected a very good agreement between the predicted and measured values. There is a good indication to predict and estimate the water flow characteristics of the gated pipe.

Key words: Hydraulic characteristics, water flow, gated pipe, simulation model, water distribution.

1. Introduction

Improving surface irrigation by using gated pipes (GP) provides an important new tool. The use of a gated pipe irrigation is claimed to be one of the ways to improve the efficiency of the surface irrigation method. [1]Reported that the irrigation application efficiency of improved gated pipes can reach up to 81%. Gated pipes, irrigation distributes water to the crop from individual gates along the pipe. Gated pipe irrigation utilizes portable rigid pipes or flexible tubing with uniformly-spaced and manual adjustable outlets for diverting water into the furrows. Uniform water flow from each outlet is regulated by sliding gates adjusting the size of the outlet opening manually to get the desired flow along the pipe[2]. [3]The hydraulic characteristics of rectangular – gated pipes were studied by observing the distribution uniformity of flow, pressure along the pipe and the discharge coefficient for the gate. Results included that: (1) laboratory work to calibrate sliding gates under different pressures, outlet areas and discharge coefficients, (2) theoretical determination of suitable outlet area to give high distribution uniformity by a new mathematical approach, and (3) fieldwork to examine the results under calculated outlet areas along 6" (150 mm) gated pipe. Results also showed great agreement the theoretical gated pipe flow rate, based on newly derived equations and the corresponding fieldwork. In another point of view, the gated pipe irrigation system does not reach the optimal water distribution uniformity, because the farmer cannot adequately adjust this system.

[4]Stated that the performance analyses the design of a Self- Compensating Gated Outlet (SCGO) found that the average discharges 29 l min^{-1} were obtained at pressure range of (5 – 9 kPa) coefficients of variation of less than 0.9 %, and head exponent close to zero. The modified gated pipe system, or self-compensating gated pipe (SCGO), usually has an internal piece of flexible diaphragm inside the gate changes shape to maintain constant pressure along the pipe[4,5]. [6]Undertook experiments to determine the outlet characteristic equation for the Flexiflume outlets (with and without the adjustable gate inserts installed) and the friction loss characteristic of the fluming with the gates installed (and protruding into the flow). Pressures were measured using a bank of 10 manometers, with a tapping point immediately upstream of each gate (installed at 1, m spacings). The outlet discharges were determined using a collection bin and an electronic flow meter with an accuracy of 5%. The combined head-discharge data for two sizes of Layflat,(222.8 and 425 mm internal diameters) were used to give the following gate characteristic equation (for the outlets without the adjustable gate inserts):

$$Q_o = 7.96\ H_p^{0.499} \tag{1}$$

$$Q_o = Cd\ A_o \sqrt{2gH_p} \tag{2}$$

Where Qo (l s^{-1}) = outlet discharge, Cd discharge coefficient, Ao (m^2) gated area, Hp (m) = pressure head relative to the gate centerline and measured just upstream of the gate. Eq., (1), a two-parameter power curve, is essentially the standard orifice equation. [7]Noted that the hydraulic modeling (or simulation modeling) in surface systems is the process of mathematically describing the hydraulic characteristics of water as it flows from one end of the field to the other. The models permit evaluation of the components of the water balance that cannot be practically measured such as the distribution of applied depths. The application of hydraulic modeling in surface systems, the governing equations and a review of existing models is presented below. Therefore the main objectives of this work was to study the hydraulic performance analysis of self-compensating gated pipe. Determine the hydraulic equations for predicting the water flow along the pipeline, to improving surface irrigation on old land of Egypt.

2. Materials and Methods

2.1 Experimental site

The field experiment was carried out at the experimental Farm of Faculty of Agriculture, Ain- Shams University Shalakan, Kalubia Government. The aim of this study is, performance hydraulic analysis to predict water distribution for traditional and self compensating (SCGO) gated pipe irrigation technique under three spacings between gates, 0.7, 1.0 and 1.5 m, for improving surface irrigation in the old land of Egypt.

2.2 Irrigation system description

The irrigation control unit is located at the source of the water supply (well) and consists of a centrifugal pump (discharging 80 m^3 h^{-1} 30 HP and 50 m lift), media filter 48" diameter (two tanks) backflow prevention device, pressure regulator, control value, pressure gauges, flow meter, and chemical injection equipment. The main line of a nominal diameter 160 mm /6 bar PVC pipeline convey water under favorable hydraulic conditions of flow velocity and friction losses. Sub-main line of a nominal diameter 110 mm 6 bar PVC pipeline provided with a by-bass arrangement which connects fertilizer injectors. Sub-sub-main lines of a nominal diameter 75 mm /6 bar PVC pipeline extended from the sub-main line and via the system flow is diverted and distributed to the various plots. Two irrigation techniques were selected, the first system is a modified gated pipe being self-compensating gate outlet (SCGO), while the second is a traditional gated pipe. Three spacings between gates along the pipeline 0.7, 1.0 and 1.5 m, were considered. These spacings are standard manufacturer design. In the gated pipe system, the pipeline is made of PVC of 110 mm diameter, with gated outlet diameter 50 mm..

Traditional gated pipe, usually exhibits a range of pressure head variations along the pipeline as well as non-uniform discharge from orifices while the modified gated pipe system, or self-compensating gated pipe (SCGO), usually has an internal piece of flexible diaphragm inside the gate that changes shape to maintain constant pressure along the pipe.

2.2.1 Components of the developer designed (SCGO)

The developed, designed of self-compensating gate outlet (SCGO) consists of four parts, as shown in (Figure 1). **Gated outlet body:** The gate outlet body was made of a P.V.C pipe of 60 mm outside diameter. The total length of the gate outlet body is 80 mm. The grooved disk rests at the body end. **Two grooved disks:** The first is P.V.C disk of 57 mm diameter of variable thickness was inserted inside the gate outlet body. The second is four similar radial grooves were formed on the surface of the disk to perform the compensating action together with a rubber membrane. **Silicon Rubber:** membrane of 44 mm diameter, 3 mm thickness and stiffness of 26.27 N/cm. 4) **Pin:** Aluminum pin of 3 mm diameter was made to fasten rubber membrane with grooved disk. The gate outlet assembly section, as shown in (Figure 2).

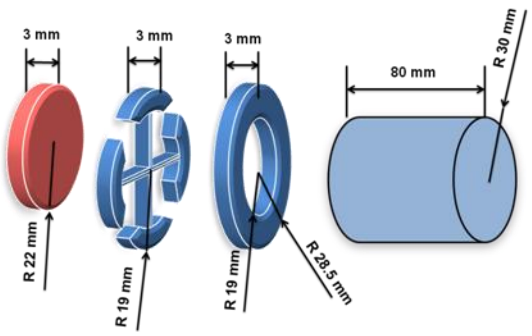

Fig. 1. SCGO details.

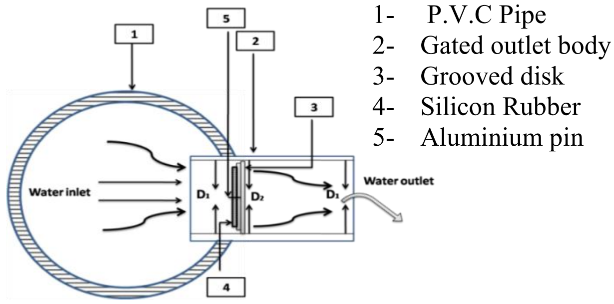

Fig. 2. Gate outlet assembly section.

2.3 Hydraulic analysis of the irrigation techniques

The hydraulic performance analysis of traditional and self-compensating gate had been conducted as a primary concept to design the simulation model for predicting water distribution.

2.3.1 Hydraulic analysis of self – compensating gated pipe

A. Performance analysis of designed components

To measure the discharge ($l\ s^{-1}$) for (SCGO) of 50 mm diameter under pressure range from 0.01- 0.28 bar with an accuracy measured of 0.01 bar was used Pressure gauge. Water establish constant pressure for (SCGO) calibration and change the pressure use control valve before gauge.

B. Gate discharge

The discharge of gate was determined at different pressure-heads. The following formulas were used to calculate average discharge and discharge range [3].

$$q\ mean = \frac{q\ min. + q\ max.}{2} \qquad (3)$$

$$q\ rang\ \pm\% = \frac{q_{min. or max} - q_{mean.}}{q_{mean.}} \times 100 \qquad (4)$$

$$q_{av.} = \frac{\Sigma q}{n} \qquad (5)$$

Where: q: discharge, (l s^{-1}), n: number of measured points,

$q_{mean.}$: mean discharge, (l s^{-1}), $q_{min.}$: minimum discharge, (l s^{-1}),
q_{Max}: maximum discharge, (l s^{-1}), ∑q: summation of discharge, (l s^{-1}), q_{av}. Average discharge, (l s^{-1}) and q_{Rang} ±: discharge variation, %.

C. Coefficient of variation

Hydraulic design of lateral-line is usually based on a design criterion[8,] using an emitter flow variation.

$$CV = \frac{S}{q} \qquad (6)$$

"S" is the standard deviation of emitter flow and "q" is the mean emitter flow. The manufacture coefficient of variation (CV)

Table (1): Classification of emitter coefficient of manufacture variation (CV).

Classification	Drip and Spray	Line source tubing
Excellent	CV < 0.05	CV < 0.1
Average	0.06 < CV < 0.07	0.1 < CV < 0.2
Marginal	0.07 < CV < 0.11	
Poor	0.11 < CV < 0.15	0.2 < CV < 0.3
Unacceptable	0.15 < CV	0.3 < CV

Manufacturing coefficient was calculated for the designed gate outlet to determine its effect on the total variation caused along lateral-line,[8].

2.3.2 Field measurements and calculations

1. Measuring discharge, of 50 mm diameter gates along the pipeline at 0.7 -1.0-1.5 m spacings for both traditional and modified gated outlets under different operating pressure ranged from (0.08-0.28) bar.
2. Uniformity coefficient **(**CU).

$$CU = (1- |\delta|) \times 100 \qquad (7)$$

Where: CU: uniformity coefficient

| δ | : Absolute mean deviation of discharge on a long line of pipe[9].

2.4 Theoretical and equations to predicting gates outflow from a long pipeline

2.4.1 Hydraulic and energy grade lines

The flow of real fluids through pipes results in a loss of energy or head along the direction of flow. the Bernoulli equation can be applied as follows:

$$\frac{P_1}{\rho g} + \frac{\alpha V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{\alpha V_2^2}{2g} + Z_2 + h_f \qquad (8)$$

Where, hf. is the head loss over the pipe length L. There is always such an energy loss associated with flow. It is graphically represented as a gradient in pressure head i.e. a hydraulic grade line (HGL) or a gradient in energy or "total head", that is, an energy grade line (EGL).

2.4.2 Friction losses in the main pipe

$$h_f = L \times \left[\frac{V}{0.849 \times CHW \times (R)^{0.63}}\right]^{1.852} \qquad (9)$$

That an equation to describe the energy loss hf due to pipe friction of each length L between the outlets, in this case the Hazen-Williams equation: Where: V, is the velocity of flow in the pipeline, (m s^{-1}); C_{HW} , Hazen-Williams coefficient; (PVC equal to 150) R, is the hydraulic radius of the pipe = D/4, m L is the length of the pipeline (m), and h_f., the friction losses (m)[12].

2.4.3 Minor losses

Change in flow velocity due to change in the geometry of a pipe system (i.e., change in cross-section, bends, and other pipe fittings) sets up eddies in the flow resulting in energy losses.

$$h_v = K \times \frac{v^2}{2g} \qquad \textbf{(10)}$$

Where:

h_v, is the friction losses in the valves or feting (m). K, is the minor loss coefficient and **H** is the head after valve or feting (m) [10].

2.4.4 Friction loss in the gated pipeline

Gated pipe is an example of divided manifold flow. The flow in pipeline is spaciously varied and in this case reduces approximately uniformly to zero at the closed or downstream end of line.

The obvious approach is to apply a Bernoulli type equation from outlet to outlet, but because of the computational effort required, this approach has been avoided. This has led to the development of simplified methods utilizing the F factor devised by[11]. He acknowledged the variable rate of friction loss and showed experimentally that the total friction loss in a multi orifices pipeline could be determined from that in an equivalent mainline by multiplication by a factor F. For example, if the **Hazen-Williams equation** is used and the pipeline is being designed for an average outflow of Q_o from each of N outlets, then, according to Christiansen, the total pipe friction loss $h_{f.}$, will be given by:

$$h_{f\ at\ Pipeline} = L_s \times F_N \times N \left[\frac{V}{0.849 \times CHW \times \left(\frac{D}{4}\right)^{0.63}}\right]^{1.852} \qquad (11)$$

Where, V is the velocity of flow in the pipeline, (m s^{-1}); C_{HW} is the Hazen-Williams coefficient; L_s is the outlet spacing (m); N is the Number of outlets from the closed end; D is the Pipe diameter (m); hf is the friction losses (m). and F_N is the Factor F_N accounts for the effect on friction losses of the spatial variation of the flow[11].

$$F_N = \frac{1}{1+m} + \frac{1}{2 \times N} + \frac{(m-1)^{0.5}}{6 \times N^2} \qquad (12)$$

Where, m is the exponent on the velocity term in the relevant flow equation, in this case m = 1.852 and N is the number of outlets from the closed end[2,12]

2.4.5 Gated pipe outlet

In his classic paper,[13] reviewed the theory of manifold flow and the experimental work to that time. The following model is drawn largely from **McNown's** analysis. The flow in the immediate vicinity of an outlet is defined in Fig. 4 and 5. Clearly, mass continuity must apply at each outlet such that:

$$Q = Q_c + Q_0 \qquad (13)$$

Where, Q is the discharge in the pipe upstream of the outlet (m^3 s^{-1}), Q_c is the discharge continuing downstream in the pipeline (m^3 s^{-1}). and Q_o is discharge from the outlet (m^3 s^{-1}).

2.4.5.1 Head losses between gates

Head losses Δh between any two gates calculated by[2] in the following equation:

$$\frac{\Delta h_p}{h_v} = 1 - \left(\frac{v_c}{v}\right)^2 \qquad (14)$$

Where, h_p is the velocity head term (m), h_v is the pressure in the pipeline (m), V_c is the flow velocity downstream of the outlet (m s^{-1}), and V is the flow velocity upstream of the outlet (m s^{-1}) [12].

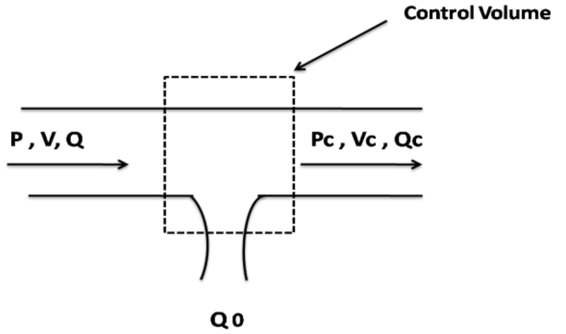

Fig. 3. Definition of symbols.

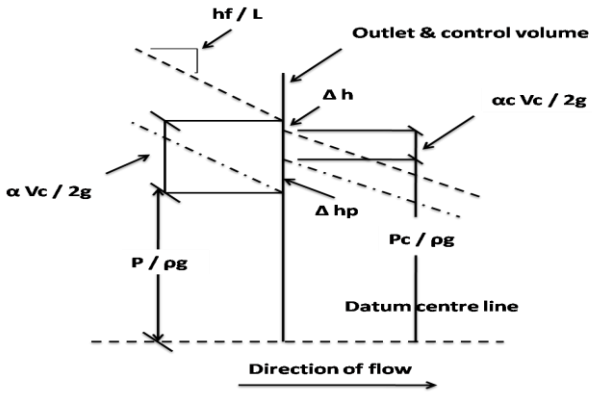

Fig. 4. Idealized energy diagram at an outlet.

2.4.5.2 Outlet discharge

The outlets or gates in gated pipe are essentially orifices and any expression characterizing their outflows would be expected to follow the standard orifice equation:[12].

$$Q_0 = C_d \, A_0 \, \sqrt{2 \, g \, H} \qquad (15)$$

Where, Q_o is the outlet discharge ($m^3 s^{-1}$), Cd is the a coefficient of discharge, A_o is the cross section area of gate (m^2), H is the pressure head (m). and g is the gravity acceleration (m s^{-1}) [12].

2.4.5.3 Outlets discharge coefficient "Cd"

Outlets discharge coefficient along the gated pipe was calculated by[10] in the following equation**:**

$$c_d = \frac{\mathit{Actual\ discharge}}{\mathit{Theoretical\ discharge}} = \frac{\mathit{Discharge\ measured\ from\ outlets}}{\mathit{Simulated\ discharge}} \qquad (16)$$

3. Results and Discussion

3.1 Hydraulics characteristics of gate designed

Figure 5 shows the discharge of gated self-compensating outlet for 50 mm diameter. Slightly increased in discharge by increasing pressure in the range of 0.01- 0.28 bar. The discharge under different operating pressure kept around 0.52 l s^{-1} for 50 mm diameter. This may be due to the reflect effect of compensation action caused by grooved disk and rubber diaphragm on discharge regulation. When the discharge between grooved disk and rubber matched with orifice flow, the developed gate outlet became compensating at pressure head from (0.06 to 0.28 bar).

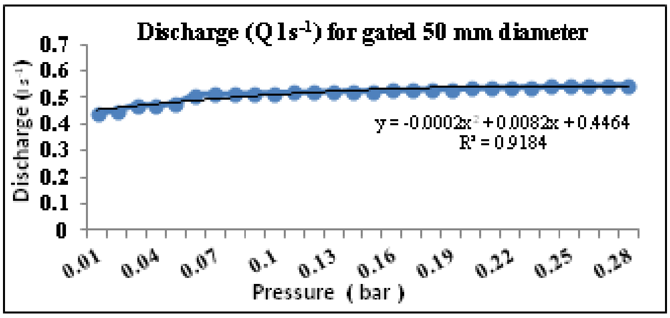

Fig. 5. The effect of pressure (bar) on measured discharge (l s^{-1}) for self- compensating gate outlet.

Results revealed that the relationship between Q and h of the SCGO gates could be summarizations follows:

$$Q_0 = A_0\,(0.0087h_p + 0.255) \qquad (17)$$

Hydraulic characteristic details are summarized in (Table 2), shows the manufacture coefficient of variation 0.09 % for 50 mm diameter when gate outlet discharges 0.52 l s^{-1}, at pressure head range of from (0.06 to 0.28) bar. The manufacture variation due to the hand making of disk groove. Variations are within **"GOOD"** category, according to[9]. The data indicated an acceptable compensating degree for tested gate outlets.

Table (2): The hydraulic characteristic details for the developed self- compensating gate outlet.

Dia.	Gate Av., q., l s^{-1}	Discharge, l s^{-1}				*C.V	**δ
		q Min.	q Max.	q Mean	±q Range%		
50 mm	0.52	0.44	0.54	0.49	10.2	0.09	0.047

* Coefficient of variation, ** Standard deviation,

In general, the theory work of gated (SCGO) as shown in (Figure 2), usually an elastic material which changes dimension as a function of pressure utilized. A flexible internal diaphragm inside the gate (SCGO) changes shape at higher pressures to create a greater restriction to flow as pressure rises.

3.2 Field measurements and calculation

3.2.1 Discharge along pipeline under different operating pressure

3.2.1.1 Discharge along pipeline for traditional gated pipe, 0.7, 1.0 and 1.5 m gates spacings under different operating pressure

[6]Have shown that any similar slight trend in the pattern of outflows was masked by the scatter in the measurements of outflow. For the Flexiflume outlets with the adjustable valves removed, outlet discharges up to 6 l s^{-1} were was measured for both pipes, while with the inserts installed and in the fully open position the maximum outflow was 2.5 l s^{-1}. All tests were conducted at pressure heads less than 1100 mm. This implies that the outlets with the adjustable valves in fully open position do not have the capacity to supply the higher flow rates required at the lower heads typically available in the furrow irrigation systems employed in the Australian cotton industry. Only by removing the valves can the desired flow rates be delivered.

Figure 6 shows the discharge (l s^{-1}), under different operating pressure (bar) for traditional gated pipe with 0.7 m spacings between the gates, 110 mm pipeline diameter, and 50 mm outlet diameter. The average measured data of discharge for first and last gate for traditional gated pipe was kept around (2.8, 4.9 l s^{-1}), (3.9, 6.9 l s^{-1}), (4.9, 9 l s^{-1}), (5.14, 9 l s^{-1}), (5.63, 10.42 l s^{-1}) and (6.18, 11 l s^{-1}) under operating pressure (0.08, 0.12, 0.16, 0.2, 0.24 and 0.28 bar) respectively.

Figures 7 and 8 shows that the trend measured for discharge l s^{-1}, with 1.0 and 1.5 m spacings between the gates were a similar to the discharge l s^{-1}, under with 0.7 m for a traditional gated pipe under different operating pressure (bar).

The data indicated that there were more variations in discharge between gates under different operating pressure for traditional gated pipe. However, there was low variation in discharge along pipeline under 1.5 m spacings, in comparison with 0.7 and 1.0 m spacings for traditional gated pipe.

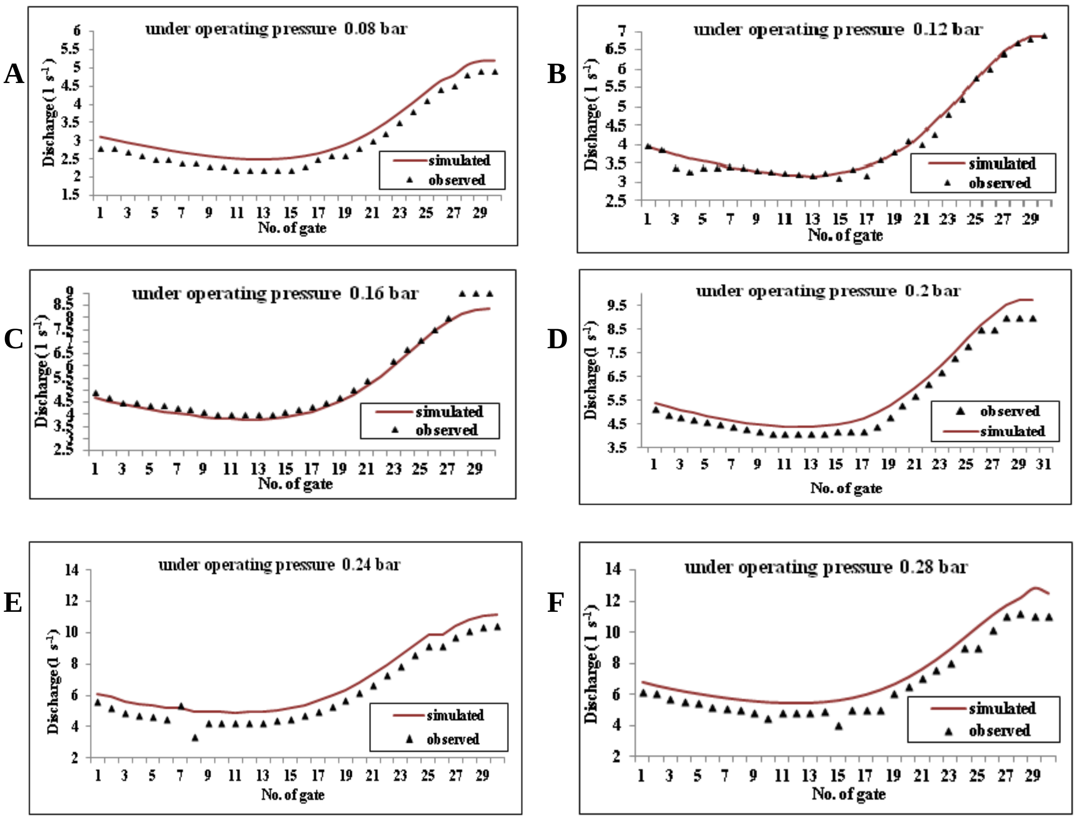

Fig. 6 (A, B, C, D, E and F). Measured and simulated discharge (l s^{-1}) of traditional gated pipe with 0.7 m, spacings between gates under pressure rang from (0.08-0.28 bar).

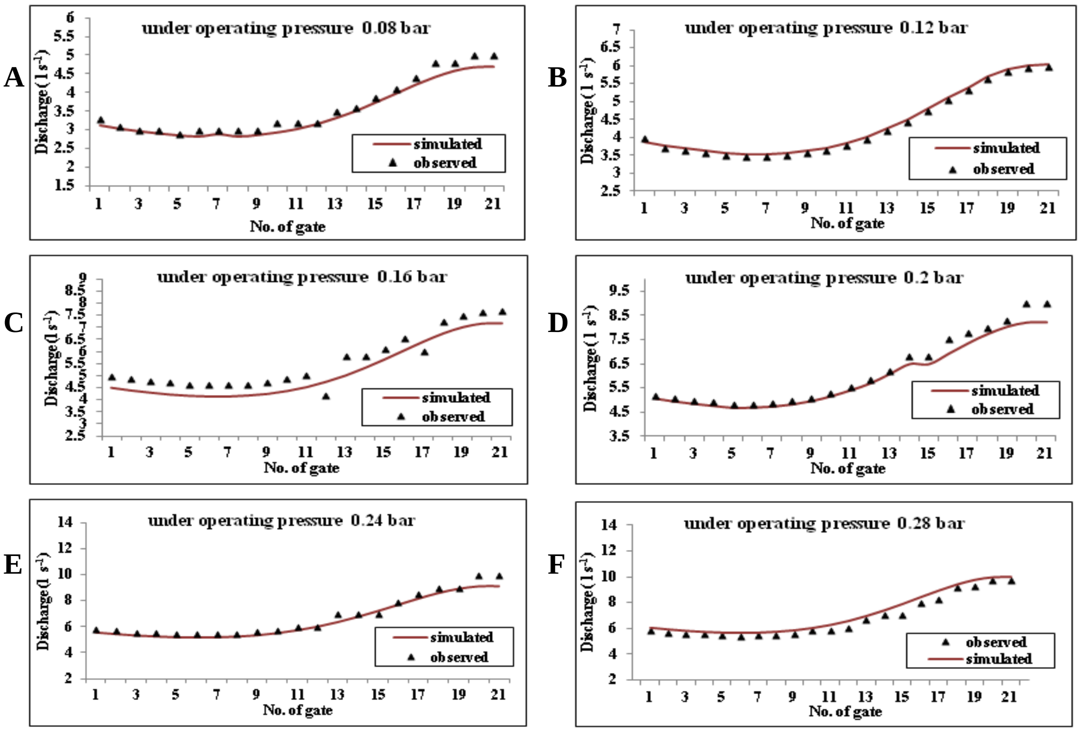

Fig. 7 (A, B, C, D, E and F). Measured and simulated discharge (l s^{-1}) of traditional gated pipe with 1 m, spacings between gates under pressure rang from (0.08-0.28 bar).

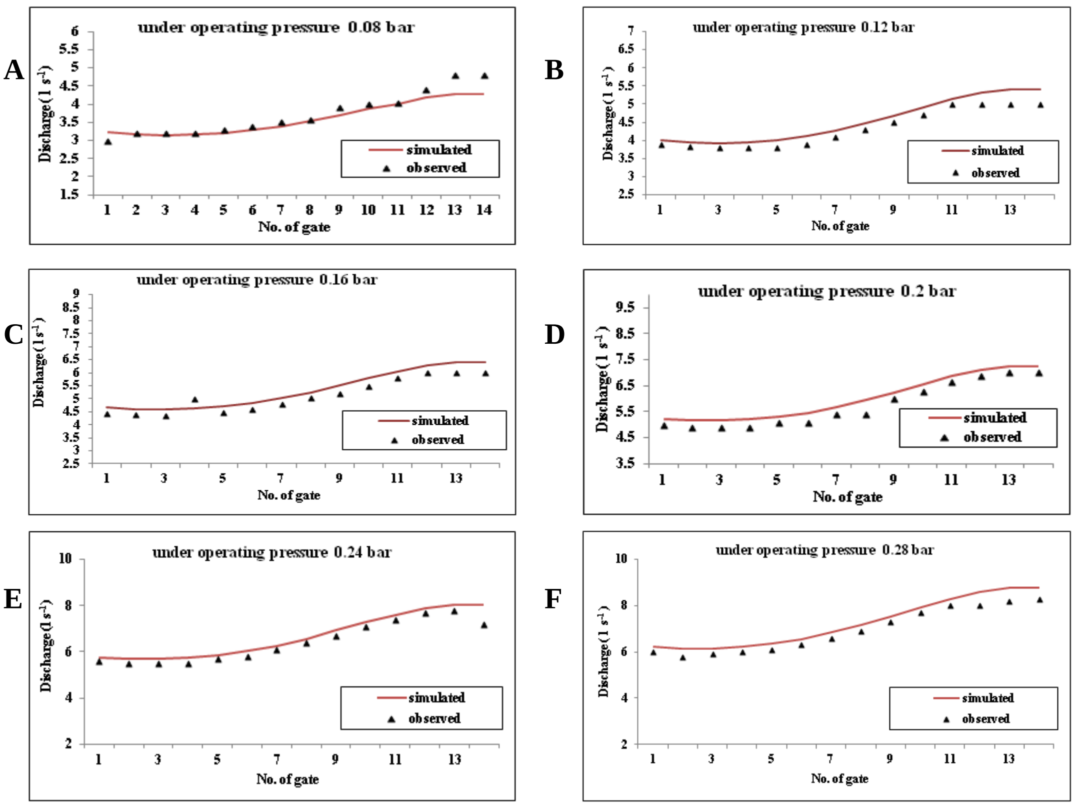

Fig. 8 (A, B, C, D, E and F). Measured and simulated discharge (l s^{-1}) of traditional gated pipe with 1.5 m, spacings between gates under pressure rang from (0.08-0.28 bar).

3.2.1.2 Discharge along pipeline for SCGO gated pipe, 0.7, 1.0 and 1.5 m spacings between gates under different operating pressure

The modified gated pipe system, or self-compensating gated pipe (SCGO), usually has an internal piece of flexible diaphragm inside the gate changes shape to maintain constant pressure along the pipe[4, 5]. Figure 9 shows that the discharge l s^{-1}, under different operating pressure bar for modified gated pipe with 0.7 m spacings between the gates, 110 mm pipeline diameter, 50 mm gate diameter. The average measured data of discharge between first and last gate for modified gated pipe was kept around (2.64, 2.59 l s^{-1}), (3.22, 3.09 l s^{-1}), (3.88, 3.76 l s^{-1}), (4.2, 4 l s^{-1}), (4.82, 4.69 l s^{-1}) and (5.2, 5.06 l s^{-1}) under operating pressure (0.08, 0.12, 0.16, 2, 2.4 and 2.8 bar) respectively.

Figures. 10 and 11 shows that the trend measured for discharge l s^{-1}, with 1.0 and 1.5 m spacings between the gates were a similar for the discharge l s^{-1}, under with 0.7 m for a modified gated pipe under different operating pressure bar. The data indicated good uniformity of discharge from each outlet being regulated along pipeline under different operating pressure for modified gated pipe for all spacing, in comparison with traditional gated pipe. However, modified gated pipe, self-compensating gate outlet (SCGO), can adjust discharge, head and uniformity of water distribution along pipeline[4].

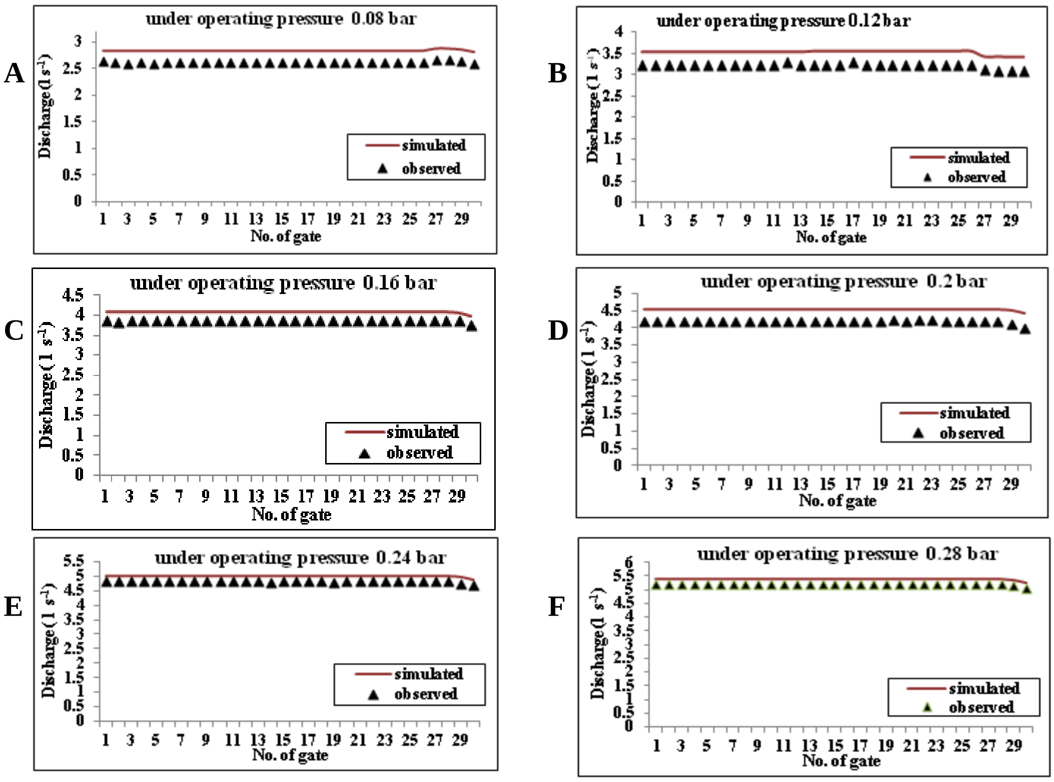

Fig. 9 (A, B, C, D, E and F). Measured and simulated discharge (l s^{-1}) of modified gated pipe with 0.7 m, spacings between gates under pressure rang from (0.08-0.28 bar).

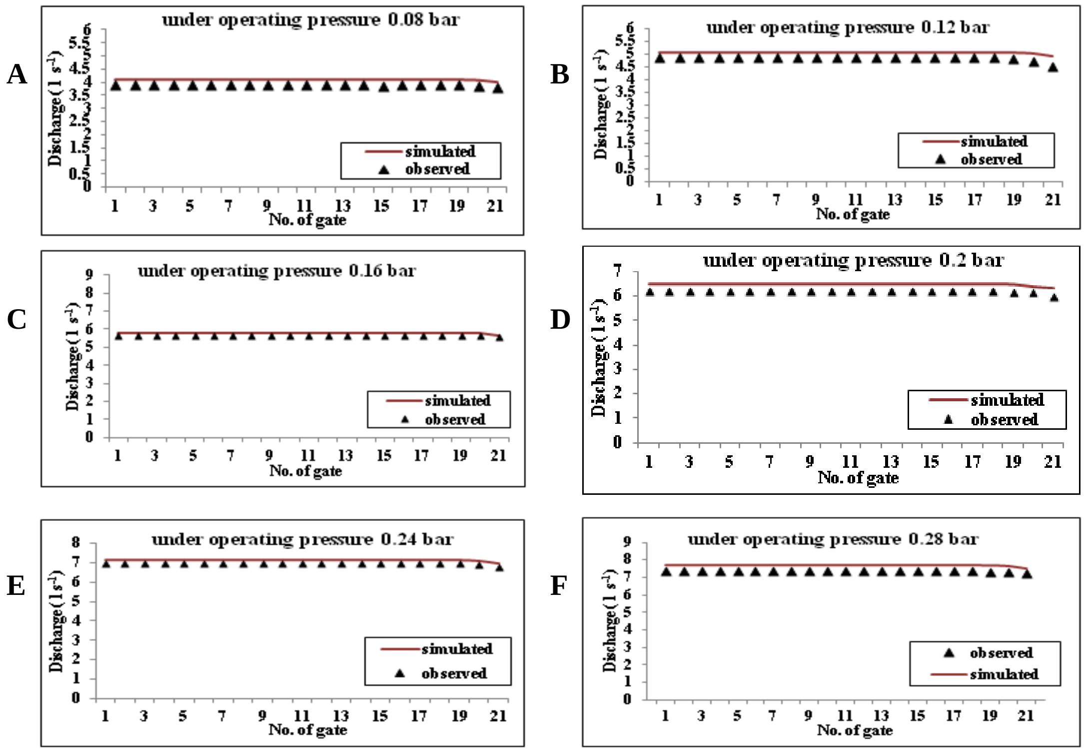

Fig. 10 (A, B, C, D, E and F). Measured and simulated discharge (l s^{-1}) of modified gated pipe with 1 m, spacings between gates under pressure rang from (0.08-0.28 bar).

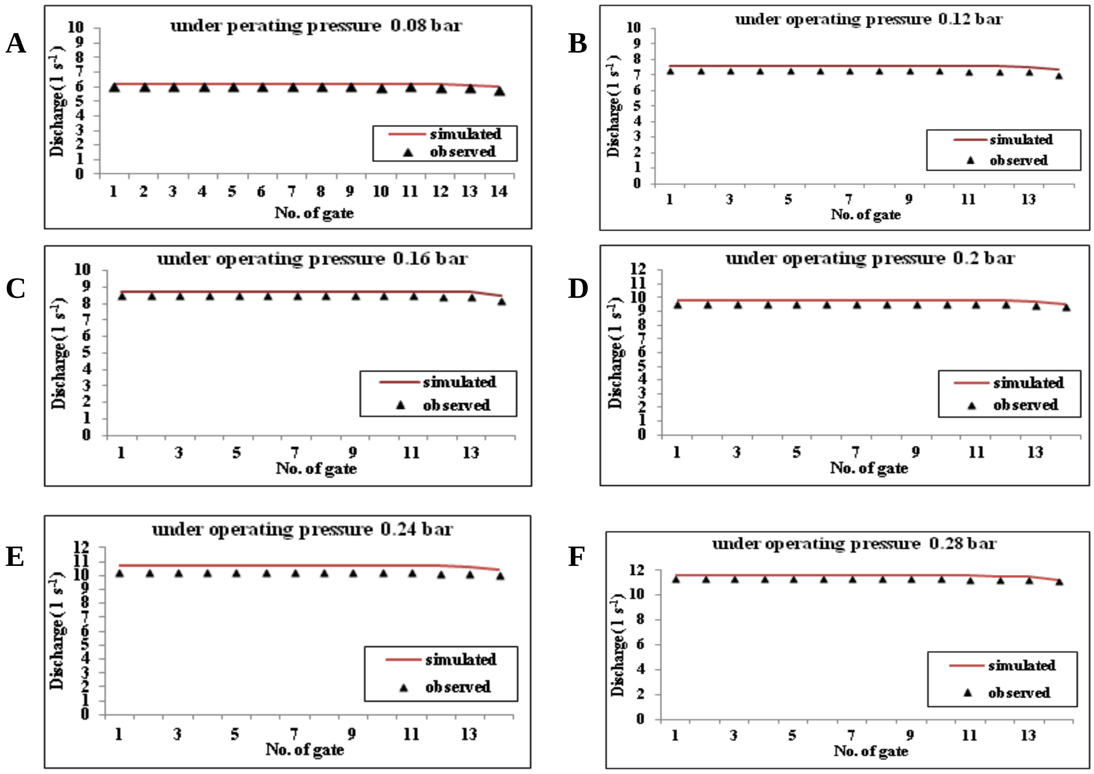

Fig. 11 (A, B, C, D, E and F). Measured and simulated discharge (l s^{-1}) of modified gated pipe with 1.5 m, spacings between gates under pressure rang from (0.08-0.28 bar).

In general, the results could be concluded that, uniform discharge was obtained at SCGO gated pipe under pressure range of 0.08- 0.28 bar.

3.3 Uniformity coefficient of distribution

Results indicate that, the average uniformity coefficient of distribution, 82.7% and 96.3% for traditional and SCGO gated pipe respectively. The increase in (UCD) is due to (SCGO) was designed to compensate pressure and improving uniformity of discharge from each outlet gates along the pipeline. The uniformity considered **"GOOD"** values for irrigation systems according to [9].

4. Conclusion

In the current study, the experimental results indicated that, the discharge was measured for design of self-compensating gated outlet. In general, there was a slight variation in discharge for SCGO under pressure in the range 0.01 – 0.28 bar. That reflects the effect of compensation action caused by grooved disk and rubber diaphragm on discharge regulation. The developed gate outlet became compensating at the pressure head from 0.06 to 0.28 bar.

The water discharge was measured in the field for traditional and modified gated pipe of 0.7, 1.0 and 1.5 m spacings between gates. In general, there was a slight variation in discharge between the first and the last gate of the modified gated pipe under 0.7, 1.0 and 1.5m spacings. The data indicated good uniformity of discharge from each outlet being regulated along the pipeline under the modified gated pipe for all spacings as the SCGO automatically adjusts its discharge, pressure head and uniformity of water distribution along the pipeline. The data of the traditional gated pipe showed a slight variation in discharge between gates under the 1.5 m spacing between gates, while there was more variation in discharge between gates under 0.7 and 1.0 m spacings between gates. The relationship between measured and predicted values of discharge along the pipeline for traditional and modified gated pipe under gate spacings, reflected a very good agreement between the predicted and observed values.

Acknowledgments

This research was funded by the Science and Technology Development Fund in Egypt, (STDF), Short Term Fellowship program, through the project "A simulation model for predicting water distribution under self compensating gated pipe irrigation technique for small holdings." The authors are grateful to the Science and Technology Development Fund in Egypt, its staff members for the support to carry out the work. Thanks are also extended to the technical staff of the Water Relations and Field Irrigation Department, National Research Centre and the technical staff of the Agricultural Engineering Department, Faculty of Agriculture, Ain Shams University, Egypt.

5. References

1. Goyal, Megh R. (2014). Management, Performance, and Applications of Micro Irrigation Systems. Research Advances in Sustainable Micro Irrigation. CRC Press, 19 Aug 2014 - Nature - 374 pages. 1771880694, 9781771880695.
2. Smith R. J. and Gillies, M. H. (2010). Head Ditch Hydraulics And The Variability of Windows To Irrigation Furrows. Irrigation and Drainage 59(4): 442-452.
3. El-Awady, M. N., El- Tantawy, M. T., Hassan, S. S. and El- Ashhab, A. O. (2003). Water Flow Uniformity Through Irrigation Gated Pipes. http://afeid.montpellier.cemagref.fr/mpl2003/ AtelierTechno/AtelierTechno/Papier% 20Entier/N50-Egypt-Gated%20Pp%20Ppr.pdf.
4. EL-Shafie, A. F., Osama, M. A., Hussein, M. M. and El-Gindy, A. M. (2009). Performance Analysis of Self–Compensating Gated Pipe For Improving Surface Irrigation Efficiency. MISR J. Ag. Eng., 26(3): 1318- 1335.
5. El-Hagarey, M. (2015). Innovative Automatic Self-Compensating Gated Irrigation Pipes Edition: https://www.lap-publishing.com/, Publisher: Publishing house: LAP LAMBERT Academic Publishing, Editor: Mohamed ElHagarey, ISBN: 978-3-659-71286-9.
6. Koech, R. K., Smith, R. J. and Gillies, M. H. (2013). Hydraulics of Large Diameter Gated Flexible Fluming. J. F. Biosyst. Eng.; 114(2): 170–177.
7. Koech, R. K. (2012). Automated Real Time Optimisation for Control of Furrow Irrigation. Ph.D, Faculty of Engineering & Surveying, University of Southern Queensland, Australia.
8. Keller, J., and Bliesner, R. D. (1990). Sprinkle and Trickle Irrigation. Van Nostrand Reinhold Newyork, avi Book P 491-492.
9. AENRI-LOFTI-MSAE. (2002). Standard for Irrigation Dripper Testing. code No: ir/dr/em/test/2002,The Ag. Eng. Res. Inst. Irrig. Proj. – Misr Soc. Ag. Eng. Standards: 5p.
10. Khurmi, R. S. (1983). A text Book of Fluid Mechanics. Pub. by S. Chand Co. Ltd Ram Nagar, NewDelhi, 11 Th. Ed : 630 pp.
11. Christiansen, J. E. (1941). Hydraulics of Sprinkler Systems for Irrigation. Trans. ASCE, 107 : 221-250.
12. Smith, R. J., Watts, P. J. and Mulder, S. J. (1986). Analysis and Design of Gated Irrigation Pipelines. Agricultural Water Management, 12(1) : 99-115.
13. McNown, J. S. (1954). Mechanics of Manifold Flow. Transactions of the American Society of Civil Engineers, 119(1) : 1103-1118.

*****