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HYDRAULIC STUDIES FOR GATED PIPES DISTRIBUTION SYSTEM

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Abstract

Theoretical and actual performance relating the engineering effective factors to water flow rates and distribution uniformity for gated pipe system were studied. The results and discussion of the study included the following aspects of the gated pipes performance: (1) Theoretical performance of circular opening of the gate, (2) Actual performance of circular opening (orifice) of the gate, and (3) Obtained different discharge rates of the gate.

The results showed that, in general, theoretical model is reliable and can be utilized to predict and compute the hydraulic coefficients of gated pipe system. The water flow rates which have been derived theoretically and actually are applicable to different surface irrigation systems. The gate discharge ranged from 0.1 to 6.0l/sec which were utilized to irrigate long furrows and long strips with length ranged from 100 m to 180 m.

Nomenclature

The following nomenclature is used in this paper.

Q	: Discharge of pumping unit, m^3/s
H_p	: Pressure head of pumping unit, cm
V_{ac}	: The average velocity inside the pipe, A*CD, cm/sec.
L_1	: Pipe length, from the inlet of pipe to the gate, m
h_{f1}	: Friction losses through the pipe of L_l length, cm
H_{th}	: Theoretical head predicted at the gated orifice = H_p-h_{f1}, cm
V_o	: Flow velocity through the gated orifice, m/sec = $(2\ gH_{gm})^{0.5}$
Q_{om}	: Predicted discharge theoretically, l/sec of gated orifice = a x Vo
Q_{oc}	: Actual discharge measurement, l/sec
Cdc	: Computed discharge coefficient, = Q_{om}/Q_{ac}
Q_p	: Predicted discharge theoretically, l/sec
Q_2	: Predicted discharge after the gate, = Q-Qom, l/sec
L_2	: Pipe length after gate, m
h_{f2}	: Friction losses after the gate, cm

h_{ft} : Total friction losses, cm
V_l : Water velocity predicted after the gate, m/sec = Q_2/A.cd
h_s : Superimposed head (Head due to decreasing water velocity), cm
CD_o : Reference discharge coefficient = 0.65
V_{oa} : Flow velocity through the gate due to actual measurements cm/s.
H_E : Computed head at the pipe end = h_p+h_s - h_{ft} cm.
H_{gm} : Actual pressure head at the gate, cm
H_{Em} : Actual pressure head at pipe end, cm
Q_m : Actual gate discharge, l/sec
V_{ia} : Actual water velocity calculated due to actual measurment, cm/s.
q_c : Computed discharge based on actual measurement, l/sec
Cd_a : Discharge coefficient calculated due to actual measurement
H_{sm} : Superimposed head pressure due to decreases of actual water velocity, cm.
A : Cross-sectional area of the pipe, cm^2
a : Cross-sectional area of gated orifice, cm^2.

INTRODUCTION

Surface irrigation is the prevailing system for growing crops in the world, specially in the arid and semi-arid areas. Recently Egyptians are looking for better irrigation systems that enable more uniform water application, improve management and reduce the risks of low crop yields or crop failure caused by poor distribution of water. Hardware such as valves and gated pipes facilitate improving the efficiency of the surface irrigation system and to bring water on the surface to be wetted (control the discharge and/or the pressure of the flow).

For this reason improving surface irrigation system performance is a major goal for the concerned organizations. National Water Research Center, Agricultural Research Center and Egyptian Universities have been working to improve the system performance. Gated pipe is one of the techniques where water flow could be controlled for better uniformity and efficiency. The gated pipe sytem consists of a single gated pipe line installed in a series of level sections at both the upper end and middle of the field Humpherys (1986). Gates in pipes feeding the different furrows should be open at the same time. This system can be easily automated to minimize irrigation labor and energy. With water available on demand, light frequent irrigation can be applied to achieve irrigation application efficiencies above 90%. The life expectancy of this system was estimated to be 20 years, Hoffman *et al.*, (1990).

Jensen (1980) reported that irrigators can increase the uniformity of application of water to their furrow irrigated crops by frequent regulation of the size of stream flowing into the furrow. For this purpose gated pipe was suggested especially to be helpful. Small and easily adjusted gates in the pipe facilitate controlling of the size of the stream deliver to the furrow stream as small as 0.1 lit/sec or as large as 1 lit./sec. Rates of flow are changed by altering the size of outlets, varying the number of outlets or changing of the operating head. Adjustable gated orifices minimize the effect of pressure head differentials on discharge rate.

Giles (1976), reported that, the coefficient of discharge depends on Reynolds number of flow in the pipe whereas Kincald and Kemper (1982) conducted a laboratory test to determine the effect of flow velocity head on the orifice discharge coefficient. Their results indicated that, for any given orifice the coefficient of discharge (cd) tended to approach a constant maximum value "Cdo" as the head increased or the velocity decreased. The value of "Cdo" varied from 0.62 to 0.65. Histing Co (1986) and other gated pipe manufacturing companies recommended that in ideal situations velocities in gated pipes should stay around 5 ft/sec (1.5 m/sec) and should never exceed 8 ft./sec (2.4 m/sec). At the high velocities gated pipe systems do not deliver water from gates properly, and in some cases water will not flow from a gate at all. Kruse *et al.* (1980), reported that gated pipes have placed siphon tubes in many cases. There are several descriptions for gated pipes, however there are no significant differences between them. Meanwhile, Zimmerman (1966), reported that aluminum or galvanized iron gated pipe is the costliest of all types of gated pipe.

Booher (1974), Miron (1979), Jensen (1980), Kember *et al.*, (1981), Kincaid and Kember (1982), Eisenhawer *et al.* (1985), and Hassan, (1990) mentioned that the major factors affecting the distribution from outlet along gated pipe system are: (1)- The main pipe diameter, (2) outlet diameter, (3) outlets spacing, (4) outlets number or the total length of the main pipe having outlets, (5) main pressure head from pumping unit (6) discharge rate from pumping unit, (7) friction losses through the total length, and (8)- the pressure head generating due to decreasing in flow velocity through the pipe.

Morcos *et al.*, (1994) stated that, the determination of the resultant pressure heads inside the perforated tubes could depend to great extent, on the theoretical and mathematical calculations, in order to design an accurate perforated tube system for conveying and distributing irrigation water. Rady, (1993) found that by using gated pipes to irrigate long furrow (100m, long) resulted in saving the water by 20%, 38% and 18% and increasing the water use efficiency by 58%, 26% and 17% for beans, corn and peas respectively, in comparison to conventional surface irrigation method used short furrows (6-10 m long) in sandy soil (Anshas region). The objective of the present paper is to calibrate the performance of local manufactured gate and to study its hydraulic coefficients considering wide range of stream size which fits surface irrigation systems.

MATERIALS AND METHODS

1- The mathematical approach :

The following are the formulas used to calculate the various hydraulic parameters required, for selecting the gate size and to predict the performance of the gated pipeline.

1. Tube inside cross sectional area "A", cm^2

$A = \pi D^2/4$

2. Area of the gate at fully opening "a"

$a = \pi d^2/4$

3. Maximum flow rate at the pipe "Q"

Q = A x Vmax

4. Frictional losses h_f determined from Hazan-Williams formula:

$h_f = 1.2 \times 10^{-10} \times (Q/c)^{1.852} \times L$

5. Superimposed head hs due to the decrease in flow velocity inside the pipe.

$h_s = (V^2{}_{maz} - V^2{}_i) /2g$

6. Resulted head inside the tube Hm and at the pipe end H_{Em} at any discharging outlet.

Hm = hp + hs-hf

H_{Em} = hp + [v2 max - v2l] / 29- $(1.2x10^{-10} \times (Q/c)^{1.852} X L)$

7. Velocity of flow inside the tube V (m/sec) just before any gate.

V= Qo/A

8. Orifice average velocity Voa of any gate

$Voa = \sqrt{29 H_{gm}}$

9. Discharge coefficient CD.

$CD = \frac{Q}{100} (0.8 - .08Vi)$

II- Experimental work

Experimental system description :

A gated pipe system shown in Fig 1 consists of a pumping unit, a conveyance pipe, two valves (one at the inlet of water flow and the other at the dead end of the pipe), a flowmeter, pointer pressure gauge and two pressure manometers. This sys-

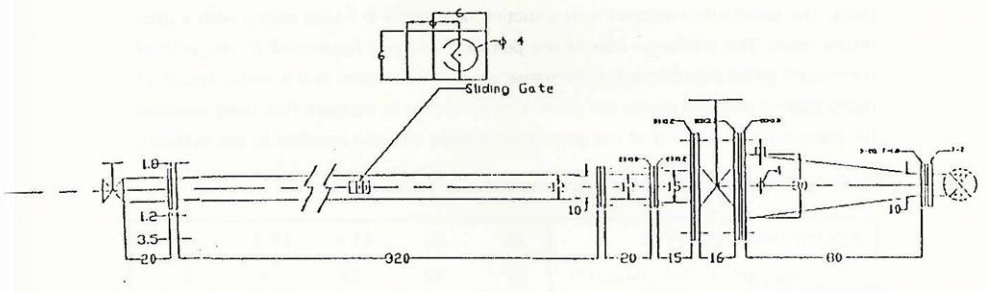

Fig. 1. The Gated pipe system .

tem supplies constant stream volumes relevent to the requirement of different planted crops at various stages of growth. The components of the gated pipe system were.

a- The pumping unit :

The pumping unit consists of one pump, the performance of the pumping unit is shown in Table (1). The pump was installed throughout connecting tubes, spool, tee and other pipe fittings in order to facilitate obtaining a variable range of discharge rates. The pump was equipped with a suction pipe and a 6 " pipe ending with a non-return valve. The discharge side of the pumping unit was connected to the inlet of the tested gated pipe through a discharge valve, a flowmeter, and 4 meter length of gated pipe. A pressure gauge and pressure manometer to measure flow head between the pumping unit and inlet of the gated pipe system was also installed to the system .

Table 1. The performance of the pumping unit.

pumping discharge, m^3/h	33	26	21.6	16.3	9
Inlet gated pipe pressure head, cm	67	42	29	25	7

b. The conveyance pipe :

Four inch (100 mm) diameter, 4 meter length aluminuim alloy pipe was used for the gated pipe system as shown in Fig 1.

The pipe drilled to form a orifice with 2" (5 cm) diameter at 1.2 meter distance from the pumping unit. The pipe was equipped by a sliding rectangular gate, (local manufacturing) having a circle orificie, made from aluminum alloy. The gate was fitted with rubber gasket to provide a water tight seal. This tested gate was operated under low and high pressure head, the gate can be adjusted by hand. The conveyance pipe is connected with a pumping unit and its dead end was equipped with a valve to control the pressure head at the dead end of conveyance pipe and the flow along the gated pipe.

c- The flowmeter:

A 4 inches flowmeter was volumetrically calibrated and used. Bypass flow from the end of the gated pipe was regulated by the valve.

d- Pointer pressure gauge with its adapter:

The pumping unit discharge head was measured using a pointer pressure gauge fixed just before the flowmeter, to be up to 6.0 kg/cm^2.

e- Pressure manometers :

Home made glass manometers were locally manufactured using 18 mm inside diameter glass tubes (to avoid the error due to capillary rise is set up by surface tension) connected with plastic hoses. Each glass manometer was fixed on a 2 meters wooden board. The plastic hose of each manometer was connected to the opening existing in the gated pipe coupler by a copper fitting. The connection between the plastic hose and the glass tube was equipped with a 4 ways copper fitting to 2 differential manometers. These 4 ways fitting were fixed on the wooden board through flexible wires to keep the inlet of the differential manometer at the same level of the central axis of the gated pipe. The purpose of using these differential manometers was to measure the difference in flow pressure between each two consecutive couplers.

RESULTS AND DISCUSSION

1) Theoretical performance of the gated orfice.

The theoretical hydraulic coefficients of the gated orifice based on the actual measurements of discharge flow rate and pressure head of the pumping unit were presented in Table 2. Data shown the discharge rates of pumping unit, the value of both the expected head at the gate and its computed discharge.

Table 2. Theoretical flow rate through the gated pipe system.

Q, Lit/sec	Hp, m	Vac m/sec	Qom, l/sec	CDc	hs, cm	H_E, cm
9.17	0.67	1.8	7.30	0.726	15.82	81.52
7.22	0.42	1.42	5.80	0.741	9.76	50.80
6.00	0.29	1.18	4.80	0.792	6.80	35.65
4.53	0.25	0.89	4.50	0.800	4.04	28.64
4.50	0.07	0.49	2.40	0.936	1.22	8.08

The flow through gated orifice decreased the velocity of water downstream of the flow, consequently a pressure head is generated through the pipe. As the velocity reached zero at the closed valve (at the end of the pipe), the highest value of pressure head was obtained. Data show that by increasing the flow discharge rate of pumping unit, both of the superimposed head and expected head at the end of the pipe increase.

2- Actual performance of cirular opening (orifice) of the gate:

Tables 3 and 4 show the actual hydraulic coefficients of the gated orfice corresponding to measuring discharge rates of the pumping unit.

Stream volume of the pumping unit.

Concerning the measurements of actual performance of the gated pipe system, Fig. 2 shows the relationship between the discharge of the pumping unit and measured pressure head of pumping unit, at gated orifice, and at the end of gated pipe. As expected there is an increase in both the pressure head at the gated orifice and pressure head at dead end of the pipe as the pressure head of beginning of tested unit increase.

The data presented in Table 3 and Fig. 6 indicate that the superimposed head which generated from decreasing of flow velocity at the gated orifice becomes maximum as the pressure head of pumping unit reaches maximum. It was observed that the increasing pressure head at the gated orifice and at dead end of the pipe are higher than that of the pumping unit. This can be attributed to the following:

1. It is considered that the flow through the pipe was being drawn off at uniform rate per unit length. In case of gated pipe the flow volume rate of flow across successive cross-section decreases as the distance from the point of input increases from the flow outlet of the pipe. Consequntly the velocity and therefore frictional losses of head per unite length also decreases. The changes of velocity generate inertia forces and high pressure may exit. This explains the increase of pressure head at the dead end of the pipe over the pressure head of pumping unit, which overcomes the raising frictional losses along the pipe.
2. The high pressure generated at the dead end of the pipe (closed valve) results in a pressure wave being propagation upstream which conveys the retardation of flow along pipe line. This besides the superimposed head resulting from the decrease of the flow velocity through the opening which, explain the higher pressure head at the opening over the pressure head of pumping unit.

With comparison the results obtained pressure head at the opening theoretically and actually (Tables 2&3), it was noticed that the actual head at the gated orifice is higher than the theoretical head at the opening by 5.5, 3.66, 3.75, and 0.64 cm. This increase as mentioned previously resulted from the effect of dead end of the pipe and superimposed head. Consequently the value of this increase overcomes the friction losses (1.502, 0.960, 0.150, 0.404, 0.135 cm). But the value of negative and positive of generated head pressure is not the same along the pipe and is higher beside the gated orifice. This explains the variation of decreased friction losses by increasing the pumping unit (Fig. 7). Comparing to the measured pressure head at dead end of the pipe and theoretical values, it is noticed that the percentage of pressure head differences ranged from 1 to 10% with an average deviation of 0.574. As much as the difference between actual measurement and theoretical results do not exceed 10%, so the theoretical calculations to predict the actual performance of gated orifice is considered reliable.

Flow discharge rate through gated orifice:

Table 3 and Fig. 4 indicate the relationship between flow discharge rate through the gated orifice and the measured head at the opening. The discharge rate through the opening increased as the pressure head of the opening increases. Also by increasing the flow velocity of water inside the pipe the discharge rate through the opening increases as shown in Fig 5. In contrast, the coefficient of discharge of the opening decreased as the discharge rate of the gate increased as shown in Fig 3.

Table 3. Actual hydraulic coefficients of gated orifice for the first section of the pipe (1.2 m long).

Q, L/S	Hgm,cm	Vca, cm/s	hs,cm	hfl,cm	qc1, L/S	Qac1,cL/S	Cda
9.17	71.00	3.73	17.34	1.502	7.572	5.30	0.70
7.22	44.70	2.96	8.77	0.960	6.009	4.30	0.72
6.00	32.60	2.53	8.04	0.150	5.136	3.80	0.74
4.53	28.00	2.34	5.64	0.404	4.750	3.60	0.76
2.5	7.5	1.21	2.14	0.135	2.456	2.21	0.90

Table 4 and Fig 4 show the relationship between both the pressure head at the dead end of the pipe and superimposed head and the flow discharge outlet from orifice. Both of head at the dead end of the pipe and superimposed head increased due to the increase of discharge rate through orifice.

Table 4. Actual hydraulic coefficients of gated orifice for the second section of the pipe (2.1 m long).

Q, L/S	Qac, L/S	Q_2,L/S	Va,cm/s	hf2,cm	H_{EM}, cm	hft, cm
9.17	5.30	3.90	0.764	0.536	82.30	3.040
7.22	4.30	2.90	0.568	0.310	49.50	1.270
6.00	3.80	2.20	0.431	0.186	36.70	0.326
4.53	3.60	0.73	0.182	0.038	30.20	0.326
2.50	2.21	0.29	0.057	0.005	09.00	0.140

The comparison of the theoretical and measured flow discharge of the gated orifice show a great agreement between them.

Discharge Coefficient of the gated orifice :

Table 3 shows the results of discharge coefficient of the gated orifice from computed discharge rate through the opening based on the actual measuring pressure head at the opening and actual stream volume per certain time. Fig 3 indicates that the coefficient discharge decreases as the pressure head of pumping unit of gated orifice and of superimposed head increases, meanwhile the flow discharge inlet the pipe increases. This may be due to turbulent flow where Renolds number becomes higher.

Accordingly the relationships between discharge coefficient and related engineering factors seem to fit the data adequately. There are inversely proportion between the discharge coefficient and both pressure head at the end of the pipe and superimposed head. In comparison to the computed discharge coefficient (Table 2) with actual discharge coefficient (Table 3), it is clearly that there is small deviation between computed and actual discharge coefficients.

Friction losses in gated pipe

The hydraulics of gated pipe can be divided into two sections: The first section extends from the water source (pumping unit) to the first open gate. The second section extends from the open gate to the end of the pipe. Table 4 and Figures 7 and 8 show as following:

a. The total friction losses increased as the pressure head of pumping unit increases., b. The total friction decreased as the superimposed head increases., and c. The total friction losses based on the actual measurements is slightly higher than that based on theoretical computations (ranged from 0.536 to 0.01 cm). Friction losses found comparatively small relative to of generated by deceleration. It seems probably that the discrepancy was due rather to variation in the discharge coefficient in computed results than theoretically results.

3. Discharge rates of the gate:

The actual discharge rate from the gate under different pressure heads ranged from 1.5 cm to the 100 cm. Calibration results were recorded at different positions of the sliding gate (1/2, "1", 3/2" , 2", 5/2") where the rate of flow was changed by altering the size of outlets. Discharge from the tested gate varied from 0, 1 to 6.0 l/s by adjusting the position of the sliding gate Fig. 9.

Gated pipes provide a good control technique over the irrigation stream size. It may be very useful in furrow irrigation when using the cutback method during the stages of growth of the crop. In this case a large flow is used initially and then cut-back by adjusting the slide gate.

SUMMARY AND CONCLUSION

1. The performance of the rectangular gate with cirulate orifice shows, different orifice discharge rates ranged between 0.10 lit/sec to 6.0 lit/sec. From the view point of the allowed discharge in irrigation furrow, a discharge 2 lit/sec is recommended for each one meter of furrow width. The proposed system can be used to irrigate long lines and long strips with lengths between 100 m to 180 m.

2. Pressure head needed to operate the system is fairly low (ranged between 1.5 cm to 100 cm). The required head to operate the system in the field is 50 cm or less, therefore pumping unit is not a must.

3. The results indicate that there is an agreement between the theoretical predicted hydraulic parameters and the actual measurements.

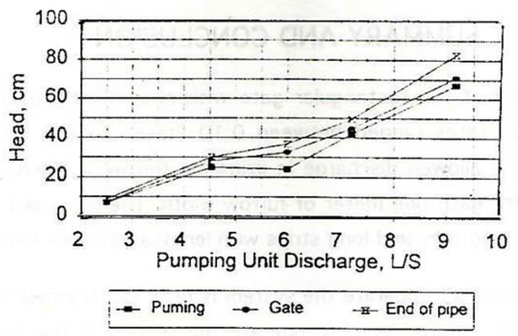

Fig. 2. Relation between pumping discharge and the head for the pump, gate and pipe end.

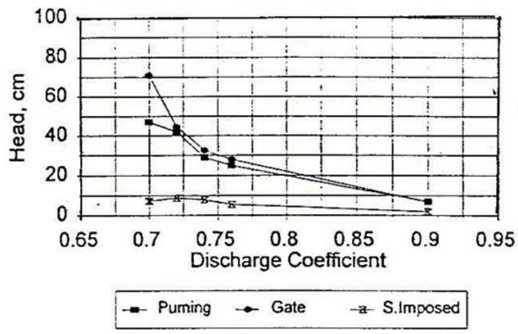

Fig. 3. Relation between discharge coefficient and the head for the pump, gate and pipe end.

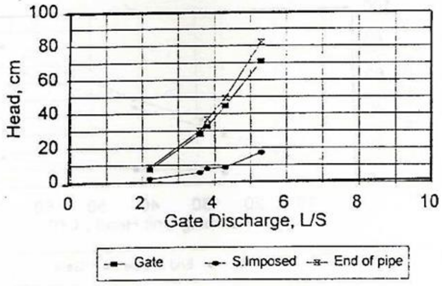

Fig. 4. Relation between gate discharge and the head for the gate, superimposed and pipe end.

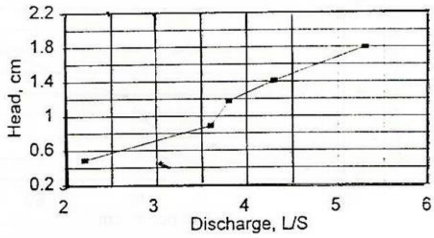

Fig. 5. Relation between discharge gate and the water velocity inside the pipe and before the gate.

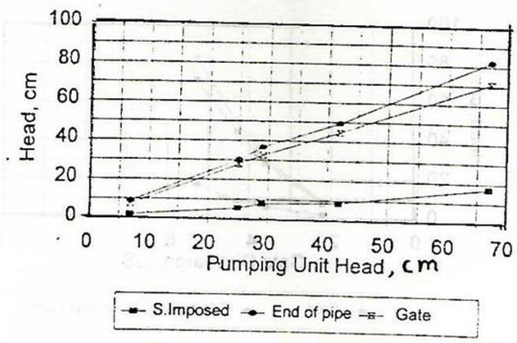

Fig. 6. Relation between pumping unit head and the superimposed head, the pipe end and the gate.

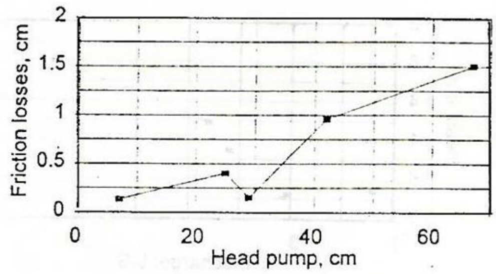

Fig. 7. Relation between discharge of pumping head and total frictional losses.

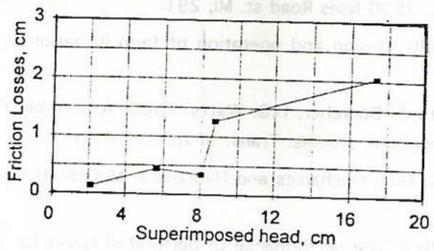

Fig. 8. Relation between frictional losses and the superimposed head.

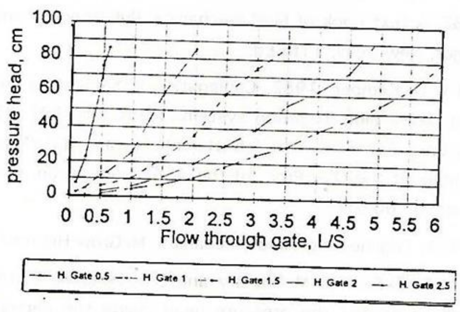

Fig. 9. Relation between pressure head and obtained discharge of gate for different areas of the gate based on the changing of the width of the gate inch .

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دراسات هيدروليكية لنظام توزيع المياه بالأنابيب المبوبة

جمال حسن السيد

معهد بحوث الهندسة الزراعية ، مركز البحوث الزراعية – الجيزة .

نظرا لمحدودية الموارد المائية المتاحة وضرورة البحث عن الوسائل التى تحقق زيادة كفاءة استخدام المياه لنظم الرى السطحى وهو الأوسع انتشارا فى مصر. فإن هذا البحث يهدف الى تقييم الأداء النظرى والفعلى لنظام الرى السطحى باستخدام الأنابيب المبوبة. ولذا فقد تم تصنيع بوابة من الألومونيوم منزلقة ذات فتحة مستديرة بقطر ٢ بوصة.

وقد تم دراسة وتقييم العوامل الهيدروليكية للأداء النظرى والفعلى للبوابة عند تصرفات وضغوط مختلفة وأظهرت النتائج ما يلى :-

١ – أمكن الحصول على تصرفات من خلال البوابة تراوحت من ٠,١ إلى ٦ لتر / ث من خلال تغيير وضع البوابة موضوع الدراسة وهذه التصرفات تناسب الرى السطحى فى خطوط طويلة تتراوح من ١٠٠ إلى ١٨٠ متر كما تفى بالاحتياجات المائية للشرائح الطويلة.

٢ – تتراوح الضغوط التى أمكن الحصول عليها والتى تعمل من خلالها البوابة موضوع الدراسة من ٥ إلى ١٠٠ سم وهذه الضغوط صغيرة مما يؤدى الى إمكانية استخدام هذا النظام بدون وحدة ضخ.

٣ – دلت النتائج على تطابق الأداء النظرى والفعلى من خلال الدراسة الهيدروليكية للعوامل الهندسية المؤثرة على هذا النظام مما يعزز من إمكانية الاعتماد على النموذج النظرى للتنبؤ بأداءها عند تصميم البوابات فى نظام الرى بالأنابيب المبوبة وتصنيعها على نطاق واسع.