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MATHIMATICAL MODEL FOR SUBUNIT DRIP IRRIGATION SYSTEM DESIGN

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ABSTRACT

A deterministic model was developed to design the subunit drip irrigation system Different pipe diameters and lengths of lateral and telescopic manifold pipe with uniform slopes were studied. The model estimated lateral and emitter discharges and pressure head distribution along a lateral and manifold starting from the downstream as well as uniformity calculation. The friction head loss between successive emitters, laterals and manifold were estimated using the Darcy-Weisbach formula. The change of the velocity head, the changes of momentum along the lateral and manifold and the loss due to emitter connection were also considered. The model for designing manifold was run successfully for supplying water to one-side and two-side laterals. Field studies were undertaken to test the validity of the computer solutions. Emission flow and pressure distributions were measured and compared quite well with those predicted from the computer model. The model has been verified under different lateral lengths, diameters and slopes, different emitter types (exponents) and barb size diameters and their interactions. The results indicated that, the average deviation percentage for 140 emitter discharges along lateral No.1, 30 and 60 (first- middle- far), were 1.24, 1.65 and 8.3%, respectively. The average deviation percentage for discharge variation, pressure head variation and uniformity coefficient for 60 laterals along manifold were 1.8, 2.1 and 2.6%, respectively. Generally, uniformity coefficient (U_C) increased with increasing lateral length until certain length then U_C remarkably decreased. The trend of U_C with lateral length has neglected difference between flat and uphill lateral up to 5% slope. While U_C improved remarkable for downhill slope with different lateral diameters. U_C tends to decrease with increasing emitter exponent and U_C remarkably decreased from 0.96 to 84% with changing slope from 5% downhill to 5% uphill, respectively for laminar emitter. Decreasing rates of U_C with increasing emitter exponent were 3.5, 9.2 and 15.7% when slope changed from -5, zero and 5%, respectively. U_C decreased with increasing barb size diameters as increasing lateral length. U_C remarkably improved with increasing lateral diameters.

Keywords: Drip irrigation, design, model, subunit, hydraulic.

INTRODUCTION

Improve irrigation techniques are essential need to increase the efficiency of water application. The accurate design of drip irrigation system is a necessary prerequisite for high uniformity of water distribution and optimum water use. The efficiency of drip irrigation systems depends directly on the uniformity which water is discharged from emission devices throughout the system. Major factors are designed emitter characteristics, pressure differences in the system due to frictional losses and elevation differentials (Al-Misned *et al*., 2000). A subunit is a part of a drip irrigation system which includes a manifold with attached laterals. The sizes of manifold and lateral lines should be designed to minimize pressure variation so the flow with equally spaced lateral lines having steady spatially varied flow with equally spaced lateral outflows (Ismail, 1993).

There are many investigations concerned on lateral design. Al-Amoud *et al*. (1997) and Hathoot *et al*. (1993) were among the first to develop lateral design procedures based on uniformity. Hathoot *et al*. (1993) consider the individual emitters, taking into account the velocity head change and the variation of Reynolds number, which affects the selection of the proper friction coefficient formula to be applied along the different reaches of the lateral pipe. Watters and Keller (1987) have reported that for smooth drip irrigation laterals the Darcy-Weisbach equation can be used for accurate estimation of the frictional head loss. They also presented graphic data on emitters' barb losses for various pipe diameters and barb dimensions. Another factor to be considered is the unit-to-unit variation with emission devices are manufactured (Solomon and Keller, 1978). This manufacturing variation of emission can have a major influence on drip system uniformity, and should not be overlooked. Ismail (1992) presented the manufacturing variation for ten emission devices commercially used in micro irrigation. Ismail (1993) developed a computer simulation model to analyze drip irrigation system design by predicting emitter pressures and discharges along laterals in the whole subunit, emission uniformity and the economically optimum pipe size.

Hanafy (1994) studied the effects of emitter spacing and the applied volume on soil moisture distribution pattern in a three dimensional profile in clay soil. Results indicated that under closer emitter spacing better uniformity in moisture distribution could be obtained along the drip tape. Also irrigation efficiency can be improved with closer emitter spacing and higher irrigation frequency. El-Morsy (1996) carried out field investigation in order to optimize the emitters flow rates and position around the tree trunk on some sloping field (15-20%). The results revealed that in the flat area the moisture was distributed symmetrically around the tree. Sharaf (2003) carried out field experiment to study the nature of pressure distribution along drip tape lateral. Pressure head change/drop and lateral flow rates were modeled with computer by three methods namely; distal outlet method (method I), Wu-Gitlin approach (method II) and near inlet method (method III). Measured pressure and lateral flow rates were made for that predicted by computer model. Comparisons were made for drip slopes of 0.2% and 0.5%. The results showed that the three methods could predict the pressure profile and lateral flow by different degrees. Method I was good, method II was better and method III was the best.

Sharaf (2004a) defined and analyzed the factors that affect the flow deviation and the economic impact of applying pressure regulated emission devices (pressure compensating). To fulfill these objectives, an analytical procedure was developed to predict the flow variation due to the pressure distribution by applying the dimensionless energy gradient concept. Results revealed that lateral slope, manifold slope, emitter flow exponent and design allowable pressure variation were the most effective variables on the discharge variation. The relationship between the discharge variation and lateral slope, manifold slope and emitter flow exponent was found to be linear function while power function was observed with the allowable pressure variation. The analysis indicated that, applying the pressure-regulated emitters could save water compared with regular emitters at the same operational conditions.

Smith (2003) and Sharaf (2004b) stated that the uniformity of micro irrigation system was influenced by total amount of water required for plant on the field. The relationship between subunit uniformity and allowable pressure variation, field topography, geometry, water temperature and pipe cost per unit area were studied. The results indicated that lateral length and slope have greater effect on subunit uniformity than manifold length and slope. The water temperature has no influence on subunit water uniformity.

In designing drip irrigation laterals it is of practical importance to have a high degree of emission uniformity. The emission uniformity allows the effects of pressure differences on the emission rate of the emitter to be evaluated separately from those of the other causes such as manufacturing variation, clogging, etc. It equal to zero when at least quarter of the emitters tested is totally clogged, Antonina and Scicolone (1998). Al-Misned *et al*. (2000) reported that, the estimation of energy losses due to emitter's connection in drip irrigation laterals is very important. Since these losses have a direct effect on drip irrigation system design, the study of these losses will lead to the improvement of system efficiency which will eventually result in conservation of water and energy.

The objectives of this work are:1- developing a mathematical model for design subunit drip irrigation system, 2- predicting each emitter operating head and discharge at any emitter and any connection between lateral and manifold under different land slopes for different emitter barb size diameter and different emitter types, 3-estimating emission uniformity (E_U), uniformity coefficient (U_C), discharge variation and pressure head variation, and 4- comparing between measured values from field experiment and predicted values.

Theoretical approach

Lateral line hydraulics design

The proposed computation model was based upon equations of conservation of mass and energy. In modeling, it was assumed that emitters on drip irrigation lines were installed at an equal spacing; *s*. The first upstream emitter was at a different spacing: s_1, from the manifold. The equation describes emitter discharge was expressed as

$$q_n = c\,H_n{}^y \quad \text{---(1)}$$

where, q_n = the discharge of emitter *n*, *c* = a emitter coefficient that accounts for area and discharge effect, H_n = the pressure head acting on the emitter *n*, and *y* = the emitter exponent constant, which depends on the state of flow and ranges between zero and 1.0.

As the lateral line has n emitters and the lateral end is closed, the discharge down stream from the emitter n should be zero, therefore, Q_n = 0.0. The lateral discharge upstream from emitter n should equal the emitter discharge; $Q_{n-1} = q_n$.

In modeling, the conservation of energy equation through lateral line between emitters n and $n-1$ was used as expressed by Hathoot *et al*. (1993). The equation was based on the Darcy-Weisbach friction head loss, the momentum effect resulting from decreasing the discharge through lateral from Q_{n-1} to Q_n, and a lateral having a uniform longitudinal slope S_o. The pressure head acting on emitter $n-1$ was given by:

$$H_{n-1} = H_n - \frac{3}{2gA^2}\left[(Q_n + q_n)^2 - Q_n^{\,2}\right] + \frac{8 f_{n-1}\ s\,(Q_n + q_n)^2}{\pi^2 g D^5} \pm s\ S_o \text{-------(2)}$$

Where, A = the cross-sectional area of lateral, g = the acceleration due to gravity, D = the lateral diameter, the positive sign corresponds to laterals sloping upwards and the negative sign is for downward slope, and f_{n-1} = the coefficient of friction in the lateral reach between emitters $n-1$ and n, which is depending on Reynolds number; R and was calculated as shown in Table 1 (Ismail, 1993).

Table 1. Friction coefficient, *f* (Ismail, 1993)

Reynolds number; R	friction coefficient, *f*
R≤2000 (Laminar flow)	$f = 64 / R$
3000≤R≤ 10^5 (Turbulent flow)	$f = 0.316\ R^{-0.25}$
10^5≤R≤10^7 (Fully turbulent flow)	$f = 0.13\ R^{-0.172}$

The head loss across the emitter barb was presented as equivalent length, which was added to the actual emitter spacing. Table (2) presents some equations for different emitters barb sizes according to Ismail (1993) based on Watters and Keller (1978) graphic data.

Table 2. Emitter barb loss equivalent length (Ismail, 1993)

Barb Size	Equivalent length (m)
Large barb (7.5 mm Φ)	$22.22\ D^{-1.77}$
Medium barb (5.0 mm Φ)	$22.41\ D^{-1.93}$
Small barb (3.8 mm Φ)	$12.41\ D^{-1.82}$
In-line	0.23

where: *D* = the inside diameter of lateral line in (mm).

Mathematical model estimates the pressure head distribution along a lateral starting from the downstream reach of the manifold line. The pressure head at the manifold; H_o was calculated from:

$$H_o = H_1 - \frac{3}{2gA^2}\left[(Q_1 + q_1)^2 - Q_1^{\,2}\right] + \frac{8 f_o\ s_1\,(Q_1 + q_1)^2}{\pi^2 g D^5} + (z_1 - z_o) \text{--------(3)}$$

where, H_1 = the pressure head at the first upstream emitter, Q_1 = the lateral discharge downstream from the first emitter, f_o = the coefficient of friction in the lateral reach between manifold and emitter$_1$, and z_1 and z_o = elevation of emitters$_1$ and manifold, respectively.

Uniformity calculation

Emission uniformity, E_U is defined as the relationship between the minimum (or maximum) emitter discharge and the average emitter discharge within a lateral.

Christiansen uniformity coefficient, U_C is a good measure of the uniformity

(Keller and Karmelli, 1974), which is given by:

$$U_c = 1 - \left[\frac{1}{n \cdot q_{av}}\right] \sum_{i=1}^{n} |q_i - q_{av}| \quad \text{-----(4)}$$

where, q_{av} = the average discharge of n emitters.

Lateral discharge and operating pressure head variations

The ASAE standards (1996) stated that to perform acceptable uniformity in drip irrigation field, the maximum discharge variation should not exceed than 10 %. The maximum pressure head variation should not exceed than 20 %. The following equations determine the maximum discharge variation and pressure head variation for lateral design. The calculation of the maximum discharge variation and pressure head variation between emitters along the lateral design were estimated for each lateral along the manifold length.

$$q_{var} = (q_{max} - q_{min}) / q_{max} \quad \text{-----(5)}$$

$$H_{var} = (H_{max} - H_{min}) / H_{max} \quad \text{-----(6)}$$

where: q_{var}= the emitter flow variation, q_{max}= the maximum emitter flow along the lateral, q_{min}= the minimum emitter flow along the lateral, H_{var}= the emitter pressure head variation, H_{max}= the maximum emitter pressure head along the lateral and H_{min}= the minimum emitter pressure head along the lateral.

Lateral allowable head loss:

David and Keller (1975) reported that, the diameter of lateral usually selected so that the difference in discharge between emitters operating simultaneously, will not exceed 10%. For 10% variation in discharge, the pressure head difference between emitters should not exceed than 20% for turbulent flow emitters. To hold cost to the minimum, it was found that the allowable head loss in lateral hydraulic design for level area should be equal to the following equation:

$$\Delta H_L = 0.55 \cdot \Delta H_S \quad \text{-----(7)}$$

where: ΔH_L= the head loss in the lateral, (m) and ΔH_S = the allowable difference in pressure head in the subunit (m).

Difference in elevation may increase or decrease the allowable friction loss. Hence, it can be noted that the cumulative friction loss along lateral did not exceed the allowable friction loss. In any other case, if the cumulative friction loss along lateral exceeds the allowable friction loss, the next lateral diameter must be selected, and the operation must restarted with the new diameter, (El-Nesr 1999)

Prediction of lateral length:

Drip irrigation lateral design can be classified into three types of design problems. 1-lateral length is unknown but pipe size is constrained, 2-pipe size is unknown but lateral length is constrained and 3-neither pipe size nor lateral length are constrained. In this study case one was considered. The objective is normally to determine the maximum lateral length, which can be utilized for pipe size while maintaining a specific uniformity coefficient of about 95%

equal an emitter flow variation of 20%.

Manifold line hydraulics design

The first assumption in manifold design is the lateral discharge; Q_L=Q_o, The discharge of last downstream segment manifold is equal to last lateral discharge, then Q_M=Q_L. The discharge of second downstream segment manifold (Q_{M-1}) is equal to last lateral discharge (Q_L) plus second downstream lateral discharge (Q_{L-1}), then Q_{M-1}= Q_L+ Q_{L-1}. The change between Q_L and Q_{L-1} was due to the segment manifold friction losses. The followed segment manifold discharge was equal to the cumulative laterals discharge and could be expressed as the following equation:

$$Q_{M-1}=Q_M + Q_{L-1} \quad \text{--(8)}$$

According to total segment manifold discharge, the modeling select first manifold pipe type and the inside diameter which, proportional to maximum discharge of manifold design. The relation between maximum manifold discharges and diameters were presented in Table (3).

Table 3. Maximum design discharge for PE and PVC manifold pipes.

PE pipe		PVC pipe	
Maximum discharge of manifold design, (l/h).	Outside diameter, (mm).	Maximum discharge of manifold design, (l/h).	Outside diameter, (mm).
Q_M < 8000.0	50.0	Q_M < 8400.0	50.0
8000 .0 ≥ Q_M < 14900.0	63.0	8400 .0 ≥ Q_M < 14100.0	63.0
14900.0≥ Q_M < 21100.0	75.0	14100.0≥ Q_M < 20000.0	75.0
Q_M > 21100.0	90.0	Q_M > 20000.0	90.0

The coefficient of friction due to different segment manifold discharge was calculated by using equations at Table (1) and the total head loss was also estimate to find the total segment manifold operating head, which was used as total operating head for second lateral. Ismail (1993) reported that, to provide first estimation for the change in the lateral discharge, the discharge of the lateral could be calculated as a function of the inlet operating head as follows:

$$Q_L = A \cdot H_{inlet}^{X} \quad \text{--(9)}$$

Where: Q_L = discharge entering the lateral, (l/h), H= operational head at the lateral inlet (m), A= constant representing the lateral diameter and dimensions and X= constant representing the flow regime of the lateral.

The modeling calculated the coefficients A and X by finding the two lateral flow rates and the corresponding inlet lateral operating pressure heads. The calculations of the coefficients A and X were estimated for every two successive lateral discharge along the manifold length. Also the cumulative friction loss was estimated and the total operating head was also determined by modeling for both of each lateral and each segment manifold. By the same way the total operating head was calculated for total manifold line to estimate the subunit water hors-power needed.

Prediction of telescopic manifold diameters and lengths:

The model selected and asked first if manifold supply water to one or two side lateral, then calculated the total segment manifold discharge. The selected diameter was chosen according to maximum manifold discharge range presented in Table (3). Also the cumulative segment manifold length was determined by the modeling. The modeling changes the diameter according to total manifold discharge.

Prediction of new average emitter discharge in previous lateral:

New emitter discharge in previous lateral was determined by using the following equation:

$$qq_n = ((COL_L - Q_{MAX})/N) + Q_{END} \quad (10)$$

$$Q_{MAX} = q_{ave} \cdot N \quad (11)$$

Where: qq_n: emitter discharge closed to lateral end (l/h), COL_L: calculated new lateral discharge (l/h), Q_{MAX}: theoretical maximum lateral discharge (l/h), N: number of emitter in or on lateral and Q_{END}: the average emitter discharge in or on lateral ($L-1$) (l/h).

Manifold allowable head loss and allowable friction loss:

The head loss in the manifold design was estimated by using equation (12), David and Keller (1975). They mentioned that, the diameter of manifold usually selected so that the difference in discharge between laterals operating simultaneously, will not exceed 10%. For 10% variation in discharge, the pressure head difference between laterals should not exceed than 20% for turbulent flow laterals. To hold cost to the minimum, it was found that the allowable head loss in manifold hydraulic design for level area should be equal to the following equation:

$$\Delta H_M = 0.45 \cdot \Delta H_S \quad (12)$$

Where: ΔH_M= the head loss in the manifold, (m) and ΔH_S = the allowable difference in pressure head in the subunit (m).

Difference in elevation may increase or decrease the allowable friction loss. Hence, it can be noted that the cumulative friction loss along manifold did not exceed the allowable friction loss. In any other case, if the cumulative friction loss along manifold exceeds the allowable friction loss, the next manifold diameter must be selected, and the operation must restarted with the new diameter, (El-Nesr 1999)

Subunit discharge and operating pressure head variations

The ASAE standards (1996) stated that to perform acceptable uniformity in subunit drip irrigation field, the maximum discharge variation should not exceed than 10 %. The maximum pressure head variation should not exceed than 20 %. Equations (5) and (6) determine the maximum discharge variation and operating pressure head variation for subunit drip irrigation design. The calculation of the maximum discharge variation (first emitter, first lateral from upstream manifold and last emitter, last lateral from close end manifold) and pressure head variation between emitters along the lateral design were estimated for each lateral along the manifold length.

Model procceding

The flow chart diagram of the main computer program is shown in Fig. (1). The main steps of the program are as follows:

Hydraulic lateral computer modeling design:

1- the essential data such as the lateral length, diameter, slope spacing between emitters, the average pressure head, the emitter constant *c* and the exponent *y*, should be known in advance.

2- the maximum lateral discharge at the upstream end of the lateral is to be calculated from:

$$Q_{MAX} = q_{ave} \cdot N \text{ ---(13)}$$

where, q_{ave} = the average emitter discharge and n is the number of emitters.

3- calculations are to be started at the downstream end of the lateral and the last emitter discharge, qn, is assumed equal to the average, qave, as a first trial cycle. The pressure head, Hn, is then evaluated by using Eq.1.

4- the pressure head at the emitter n-1, is estimated according to Eq. 2.

5- the pressure loss due to emitter barb is estimated according to Table 2.

6- the emitter discharge of the second emitter from the downstream, qn-1, is estimated according to Eq. 1.

7- the pressure head at the third emitter from the downstream is estimated according to Eq. 2 and then emitter discharge is evaluated according to Eq. 1.

8- calculations similar to those performed in step no. 5,6 and 7 are repeated for other emitters in the upstream directions until the first emitter close to the manifold is reached.

9- the pressure head at the manifold line end of the lateral, Ho is evaluated by using Eqs. 3.

10- the assumption qn = qave, is correct, which is not expected in the first trial, the estimated lateral discharge will be equal to Qmax, otherwise corrections should be made.

11- the difference Qmax – Qo, is estimated and the corrective emitter discharge to be added to the assumed qn is given by:

$$\Delta = \left(Q_{\max} - Q_o\right) / \; n \text{ ---(14)}$$

12- steps 4 through 10 are to be repeated with the new downstream emitter discharge given by

$$q_n = q_n + \Delta \text{ ---(15)}$$

13- trial cycles are continued until the difference DIF = Q_{max} - Q_o, becomes particularly small such that:

$$\frac{|100 \cdot DIF|}{Q_{\max}} \le \xi$$

where, ξ =a small quantity in the order of 0.0001 .

14- evaluation of U_c, from Eq. 4.

Hydraulic manifold Computer modeling design

15- manifold design by computer modeling is applicable for supplying water to one-side or two-side lateral. For one side lateral Qm= Ql and for two side latera Qm=2 Ql .

16- the telescopic manifold diameter was selected carefully by computer modeling according to total discharge pass through it.

17- friction loss of manifold design was calculated according to total discharge pass through it and the computer modeling is applicable for determining the allowable head, which not acceded than total manifold head, also allowable friction loss, which not acceded than total manifold friction loss Eq. 12

18- desinging subunit irrigation network was succeeded for calculating the overall discharge variation (<10%) and ovarall head variation (<20%).

19- both of emission uniformity (E_U) and uniformity coefficient (U_C) were estimated successfully and accurately by designing computer modeling for subunit irrigation network.

Design constraints and criteria

To design drip irrigation subunit, it is necessary to determine either the diameter or the length of the lateral pipe and telescopic manifold pipes with the other variable known. While determining the diameter or length of lateral, the coefficient of uniformity U_c should be equal to or greater than an acceptable level of uniformity (U_C), which is taken herein as 0.95.

The lateral pipe design is assumed that the pressure-head discharge relationship, allowable head loss, discharge and acceptable level of uniformity are known in advance. It remains to design either the pipe length or the diameter with the other variables known..

MATERIALS AND METHODS

In order to validate the model of designing irrigation subunit network, an area of 3150 m^2 (70 x 45m) at Bostan, Nubaria, Aly Mobark Village, Behera was designed by the model. The input data for modeling subunit drip irrigation system was consisting of polyethylene lateral length = 70 m, manifold length = 45 m, emitter spacing = 0.5 m (140 emitters along each lateral), lateral spacing = 0.75 m (No. of laterals along manifold = 60), in-line emitter type equation; q = 2.132 $H^{0.533}$, lateral and manifold slopes = 0%, operating emitter pressure head equal 1 bar, and coefficient of uniformity; U_c = 0.95. The model was predicted diameter of lateral pipe, diameter of telescopic manifold pipes, head and discharge of each emitter along each lateral, inlet lateral head and discharge along manifold, friction losses through lateral and manifold segment, and statistical items such as variation of emitter discharge and head, standard deviation, coefficient of variation, emission uniformity, uniformity coefficient for each lateral and as overall subunit irrigation network.

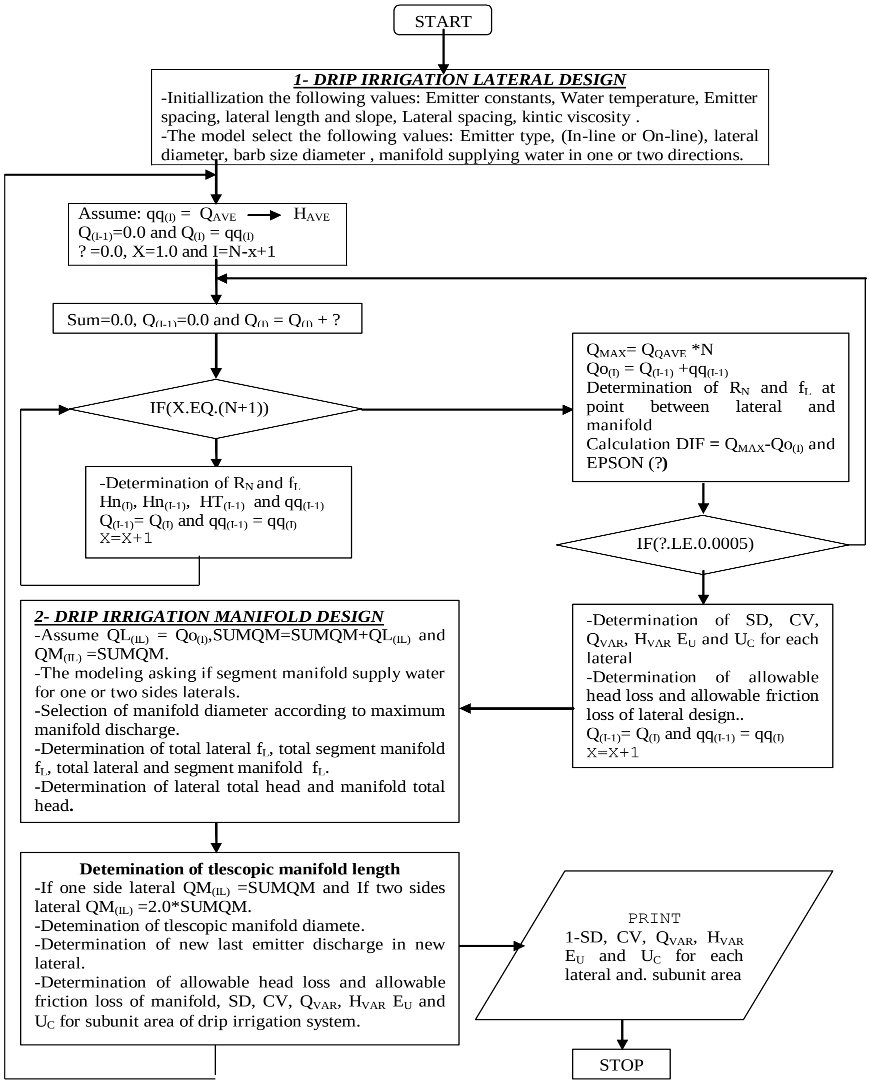

Fig. (1): Subunit drip irrigation design flow-chart

Field experiment was conducted during summer season 2008. The subunit drip irrigation network were implemented and equipped with a control head consisting of electrical centrifugal pump, non return valve, pressure regulator, sand and screen filters, control valves, pressure gauges and flow meter. For comparison between predicted data from model and field experiment data, the distribution of emitters' discharge along laterals No. 1, 30 and 60 were measured. The inlet and tail end of each lateral line along manifold were plugged with pressure gauge and recorded for three times. Water temperature was also measured to account viscosity changes.

RESULTS AND DISCUSSION

Modeling results validation

Model validation was done between the theoretical model values and the experimental observed values for each emitter discharge along lateral, discharge and pressure head of inlet lateral along manifold, lateral discharge variations (Q_{VAR}), pressure head variation (H_{VAR}) and uniformity coefficient (U_C) for lateral No.1, 30 and 60, which represented to first lateral (close to subunit valve), middle lateral and far lateral, respectively in subunit irrigation network.

Fig. (2) illustrated the measured emitter discharge along lateral distance for lateral No. 1, 30 and 60. The figure explained the distribution of emitter discharge through experiment subunit irrigation network. Emitter discharge slightly decreased with increasing lateral distance, this reduction attributed to the effect of the friction losses. The friction losses was calculated form measured discharge and emitter constants (*c* and *y*). The total friction losses were 0.122, 0.121 and 0.118 bar along lateral No. 1, 30 and 60, respectively. Meanwhile, the total emitter discharges were 304.40, 298.07 and 291.9 l/h for lateral No. 1, 30 and 60, respectively. As shown the average emitter discharges were slightly decreased as lateral far from the water source. The average measured and predicted values of emission uniformity, (E_U) for lateral (1, 30 and 60) were 96.62 and 98.58%, respectively. These results were agreement with Al-Amoud *et al*. (1997) and Smith (2003).

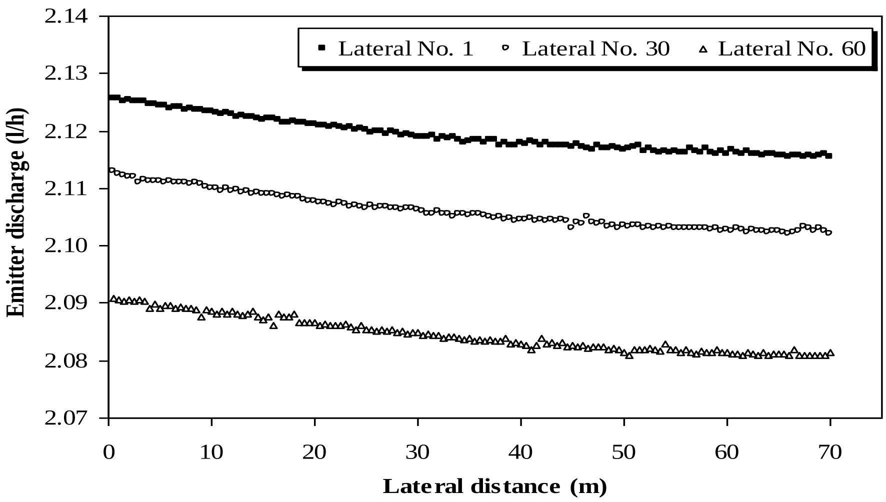

Fig. (2): Measured emitter discharge along lateral distance for lateral No. 1, 30 and 60.

Fig (3) shows the measured inlet lateral discharge and inlet lateral pressure head along manifold distance. It is notes, that inlet lateral discharge along manifold has little change ranged from 291.9 to 304.4 l/h. Inlet lateral head were slightly decreased which ranged from 1.04 bar (at lateral No.1) to

0.96 bar (at lateral No. 60) along manifold distance. The increase of segment manifold pressure head was due to high friction loss at upstream. High friction loss occurred at inlet segment manifold (closed to lateral No.1) due to large amount of water supplied. These results were confirmed with Ismail (1993).

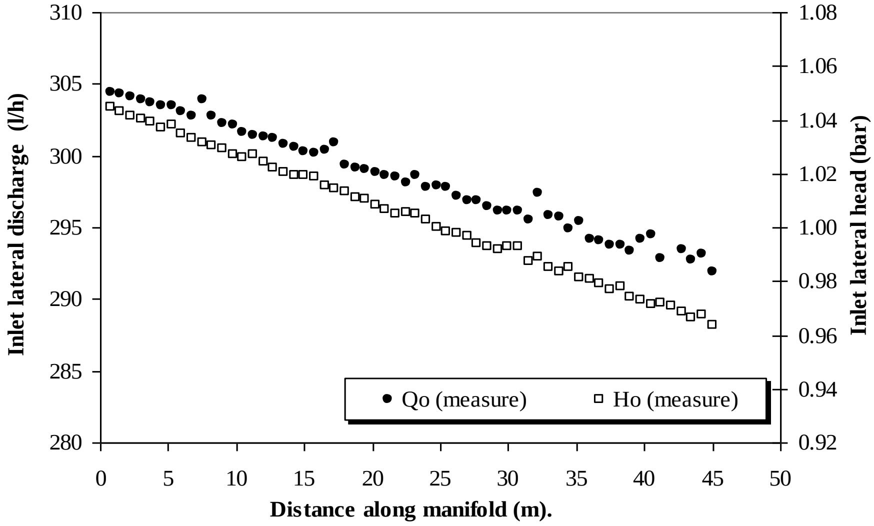

Fig. (3): Measured inlet lateral discharge and inlet lateral pressure head along manifold distance.

Telescopic manifold lengths and diameters for one or two sides lateral were predicted by computer modeling for subunit drip irrigation network. In case of one side lateral, the predicted segment manifold lengths were 10.5, 7.5, 7.5 and 18.75 meter for segment manifold diameter 50, 63, 75 and 90 mm, respectively. While, the actual segment manifold lengths installed in the field were 10, 8, 8, 19 meter for the same diameter. This means that, the computer modeling successive accurately for selecting segment manifold length with diameter fro desired U_C=98.5%. These results were agreement with Ismail (1993).

Percentage deviation was calculated as follows:

[Deviation (%) = (Measured value-Predicted value)/ Measured value].

The prediction error for each test is the average deviation percentage (by summation up the individual percentage of each value and dividing it by the number of values). Fig (4) indicated that values are close to a straight line of 1:1 slope as desired. The average deviation percentage for 140 emitter discharges along lateral No.1, 30 and 60, (first- middle- far), were 1.24, 1.65 and 8.3%, respectively. Statistical analyses showed that the determination of the correlation coefficient (R^2) between predicted and measured values of 140 emitter discharges along lateral No.1, 30 and 60, (first-middle-far), were 0.99, 0.99 and 0.99 respectively. Results indicated that the model is capable of predicting any emitter discharge (q_l) along any lateral with high accuracy. These results were confirmed with Hathoot *et al*. (1994).

Fig. (4) illustrate that the average deviation percentage of discharge and head variation were equal to 1.80 and 2.1% with correlation coefficient (R^2) 0.97 and 0.99 for 60 laterals along manifold, respectively. This means that the predicted values of discharge variation and head variation are closely agreement with the experimental observed values. While the average deviation percentage for uniformity coefficient for 60 laterals along manifold was equal to 2.6% with correlation coefficient (R^2), 0.99. High values of correlation coefficient (R^2) indicate that the predicted values are closely agreement with the experimental data. These results were confirmed with Antonina and Scicolone (1998).

Model results verification

In order to verify the model, the uniformity coefficient was examined under different lateral line conditions as following:

1- model was verified under different lengths (start from 10 meters up to 250 meters in 10 meters increments), different inside diameters (13, 16 and 18 mm) and different slopes (-5, 0 and +5%). Lateral was investigated for in-line emitter turbulent type with emitter equation q = 2.08 $H^{0.54}$ and 1 m emitter spacing.

2- different emitter types was determined by changing emitter exponent with three slopes (-5, 0 and +5%) at same emitter constant (a = 2.08), 100 m lateral length, 16 mm inside lateral diameter and 1 m emitter spacing.

3- model was verified under four installs emitter types; in-line. Small, medium and large barb size diameter was studied with different lateral length (starting from 10 meters up to 250 meters with 10 meters increments) at zero slope. Where emitter equation was q = 2.08 $H^{0.533}$, 16 mm inside lateral diameter and 1 m emitter spacing.

4- different lateral inside diameters (13, 16 and 18 mm) which, represented outside lateral diameters (16, 18, 20 mm) was determined with different installs emitter types (small, medium and large barb size diameter) and with three lateral length (100, 150 and 200 m) at zero slope, emitter equation; q = 2.08 $H^{0.533}$, 16 mm inside lateral diameter and 1 m emitter spacing.

The model has been verified under different lateral lengths, diameters and slopes, different emitter types (exponents) and emitter barb size diameters and their interaction.

Fig. (5) Presents the effect of the length (L), inside diameter (D) and slope (S_o) of lateral on the uniformity coefficient (U_C). Generally, the U_C increased with increasing lateral length until certain length, (40 m) then with greater lateral length, U_C decreased. In case of 2 l/h turbulent flow emitter (q= 2.08 $H^{0.533}$) and 1m emitter spacing, there is no effect of lateral diameter and slope on uniformity coefficient for the short lateral length (about 40 m). That was attributed due to low friction through it. The trend of U_C with lateral length has neglected difference between flat lateral and uphill lateral up to 5% slope, for the same lateral diameter, (13 or 16 or 18mm). However, the downhill lateral slope improved remarkable the U_C. Whereas, uniformity coefficient U_C will be almost constant (0.98-0.965) for lateral diameter of 16 and 18 mm with length (> 250 m), while, U_c obviously decreased for 13 mm lateral diameter and 160 m lateral length. These results could be revels that the effect of downhill slope of 5% gain energy head to equalize the friction losses. These results were confirmed with Amer and Gomaa (2003).

Fig. (5) Shows that there is a decrease in uniformity coefficient when the lateral length increases for zero and up word slop. That could be the energy loss due to lateral friction and emitter's barb, which increases as lateral increase. For down ward slope, the uniformity coefficient increases with length until it reaches the maximum value at length less than 100 meter, then decreases as the lateral length increases. The uniformity decreases with increase of slope.

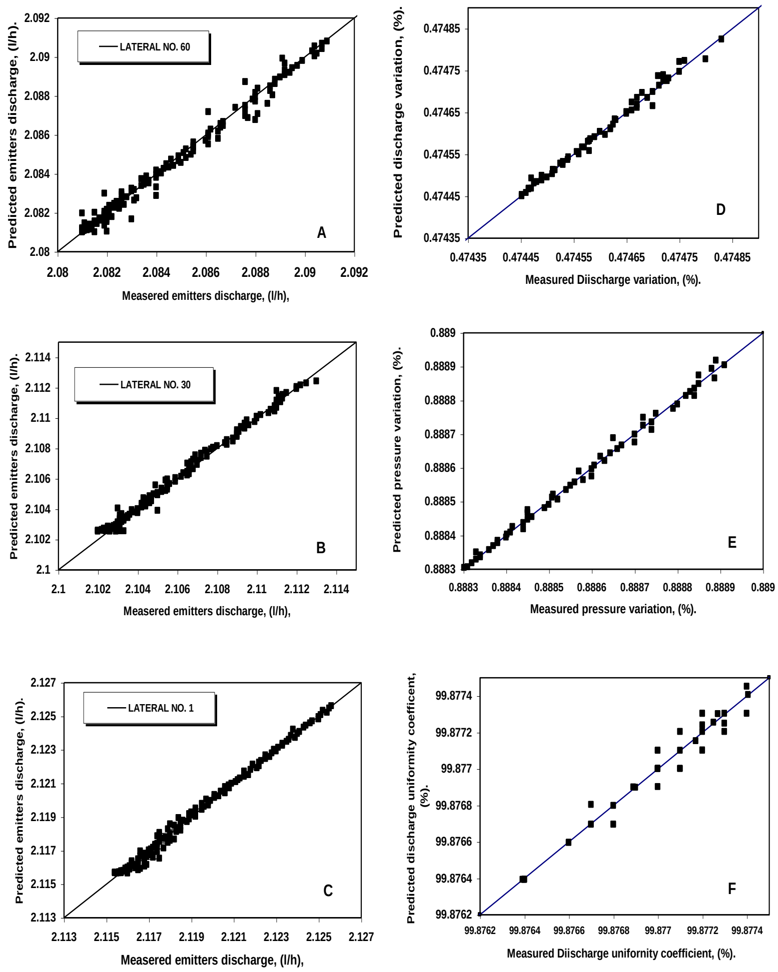

Fig. (4): Measured and predicted emitter discharge along lateral 1, 30 and 60 (A, B and C), lateral discharge and pressure head variations (D and E) and uniformity coefficient of laterals (F).

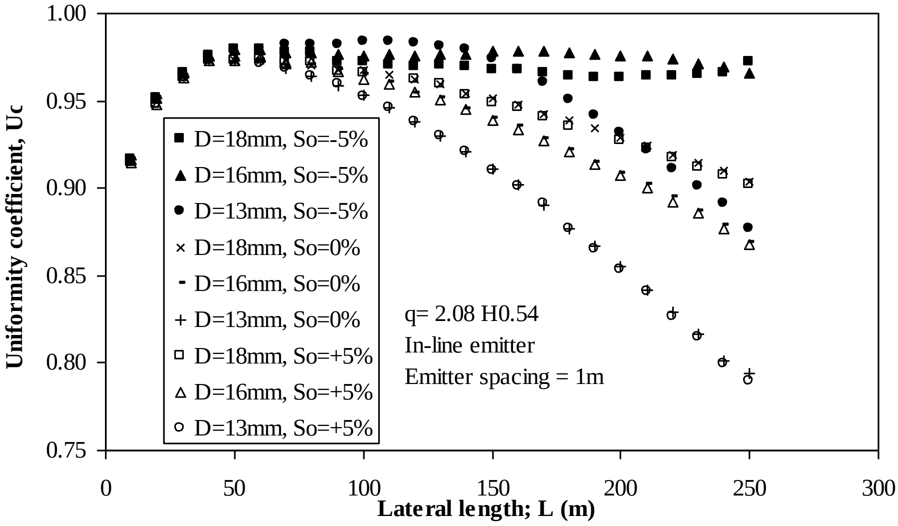

Fig. (5): Uniformity coefficient versus: lateral length as affected by lateral diameter and slope

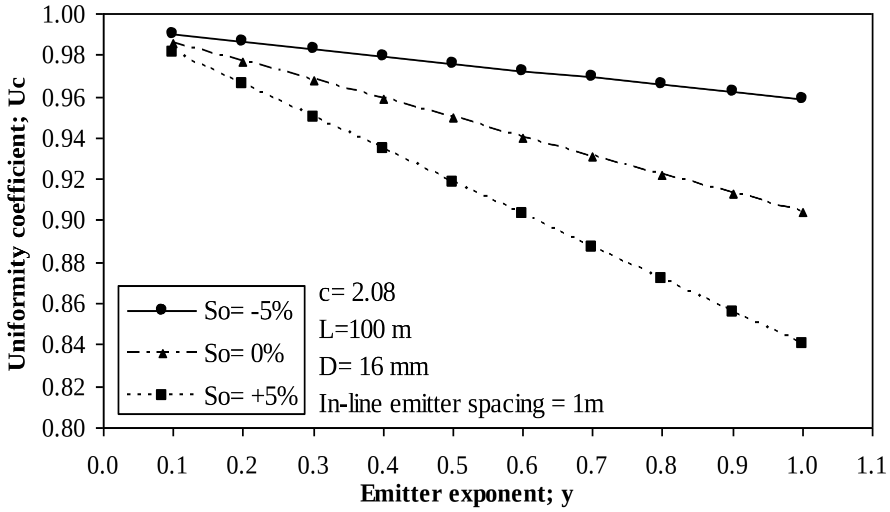

Fig. (6): Uniformity coefficient versus emitter exponent under different slope

Fig. (6) shows effect of emitter exponent (y) on uniformity coefficient. It is clear that, uniformity coefficient tends to decrease with increasing emitter exponent. It is also illustrated that the uniformity coefficient decrease remarkable from 0.96 to 84% with changing slope from 5% downhill to 5% uphill at emitter exponent equal one. This results were due to emitters group represented to laminar flow which, affected by the changing head caused by different elevation.

Decreasing rates of uniformity coefficient with increasing emitter exponent were 3.5, 9.2 and 15.7% when slope changed from -5, zero and 5%, respectively. Also the same figure shows that in case of emitter exponent closed to 0.1, there is no effect of slope on uniformity coefficient because these emitters group represented to compensating head. In case of turbulent flow (emitter exponent=0.5) the uniformity coefficient varied from 0.97 to 0.90.

Fig. (7) Clear that, uniformity coefficient affected by different lateral length and different emitter barb size diameter. Meanwhile, uniformity coefficient increased from 0.92 to 0.99 in case of increasing lateral length up to 80 meter for all barb size diameter. On the other hand, increasing lateral length than 80 meter, uniformity coefficient decreased remarkable. This could be attributed to increasing lateral cross-section lead to decrease friction loss. These results were confirmed with Smith (2003) and Sharaf (2003).

Fig (8) shows that, the influence of lateral diameter on uniformity coefficient values at different barb size diameter and different lateral length. Uniformity coefficient increased from 0.97 to 0.98 (small barb size diameter), 0.96 to 0.974 (medium barb size diameter) and from 0.9 to 0.977 (large barb size diameter) with increasing lateral diameter from 13.1, 15.6 and 17.0 mm inner diameter for lateral length 100 meter, respectively**.**

On the other hand, Uniformity coefficient increased from 0.90 to 0.97 (small barb size diameter), 0.89 to 0.96 (medium barb size diameter) and from 0.88 to 0.96 (large barb size diameter) with increasing lateral diameter from 13.1, 15.6 and 17.0 mm inner diameter for lateral length 200 meter, respectively. This due to large barb size diameter has friction losses grater than large barb size diameter and in case of In-line emitter. These results were agreement with Hathoot *et al*. (1994) and Sharaf (2004b).

For In-line emitter, decreasing uniformity coefficient values were less affected than On-line emitter, (small-medium-large)

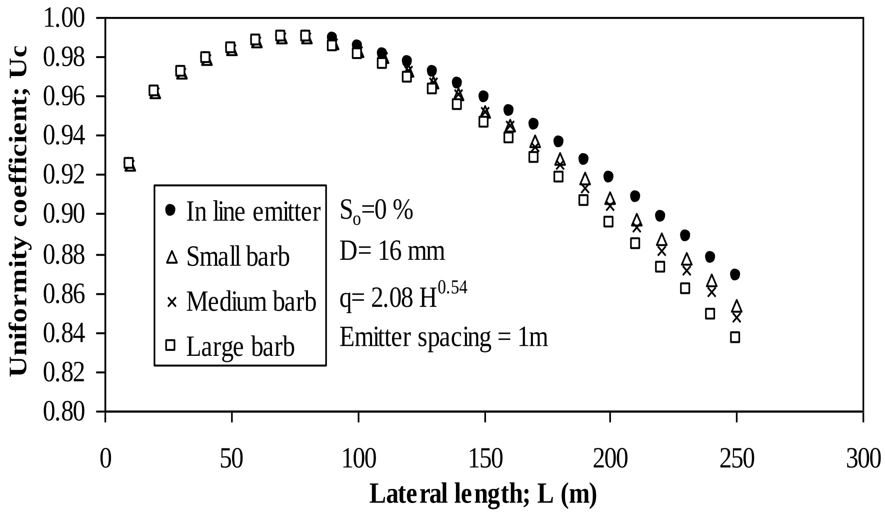

Fig. (7): Uniformity coefficient versus lateral length under different emitter barb size diameter.

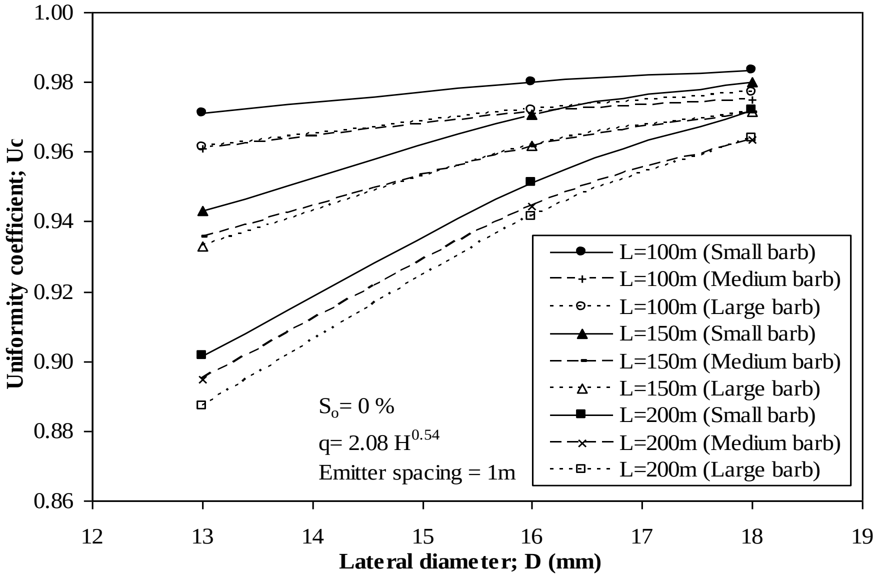

Fig. (8): Uniformity coefficient versus lateral diameter under different emitter barb size diameter and lateral length.

Conclusion

The simulation model that uses fundamental hydraulic relationships to simulate flow within subunit drip irrigation network was developed. The model takes into account the change in water viscosity due to temperature. The model is capable of predicting with successive accurately any emitter discharge (q_l) along any lateral, each emitter operating head and discharge for all laterals under different land slopes for On-line emitter with different emitter barb size diameter and In-line emitter. Hydraulic lateral and segment manifold design (discharge, operating head, diameter, discharge and operating head variation, emission uniformity and uniformity coefficient) under different lateral lengths and slopes. The measured values obtained from the experimental field are closely agreement with the predicted values obtained from model.

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نموذج رياضي لتصميم القطعة الفرعية للري بالتنقيط

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نظرا للزيادة المطلوبة لاستخدام مياه الري في الزراعة ومحدودية مصادر المياه ولثبات كمية المياه المخصصة لجمهورية مصر العربية من مياه النيل .كانت الحاجة إلي استخدام نظم الري الحديثة في الزراعة ولاسيما في المناطق الصحراوية حيث المناخ الحار وندرة المياه .لذلك اتجه البحث الي أجراء تطوير لنموذج رياضي بالكمبيوتر ذو دقة عالية في التصميم لنظام الري بالتنقيط لتحسين ورفع كفاءة توزيع المياه.

لذا كانت أهداف البحث هي: ١- تطوير نموذج رياضي بالكمبيوتر لتصميم القطعة الفرعية للري بالتنقيط (Subunit irrigation network) مشتملا التصميم الهيدروليكي لكل من خط النقاطات (Lateral line) والخط المشعب (Manifold line) والفوا قد الناتجة عن الاحتكاك والفواقد الناتجة عن اتصال النقاطات بخط النقاطات. ٢- التنبؤ بكل من التصرف والضاغط عند كل نقاط وعند كل نقطة أتصال

بين كل خط النقاطات والخط المشعب تحت الظروف المختلفة. ٣- تقدير قيم كل من أنتظامية توزيع المياه (E_u)– معامل توزيع المياه (U_C)–نسبة التغير في التصرف (Q_{VAR}) ونسبة التغير في الضغط (H_{VAR}). ٤- عمل مقارنة بين النتائج المقاسة من التجارب الحقلية والنتائج المتنبأ بها من النموذج الرياضي بالكمبيونر (Computer modeling).

تم عمل نموذج رياضي وبعد أجراء التجارب الاختبارية عليه والتأكد من صحتة ومصداقيتة ودقتة، تم تصميم شبكة ري بالتنقيط بناءاً علي ما تم الحصول علية من نتائج البرنامج وتنفيذها حقليا بمزرعة علي مبارك بمنطقة البستان بالنوبارية محافظة البحيرة خلال موسم ٢٠٠٨م واخذ القياسات الحقلية ومقارنتها بالنتائج المتحصل عليها. **كانت أهم النتائج المتحصل من البحث هي:**

١. يقل تصرف النقاطات بزيادة بعد النقاط عن بداية خط النقاطات وهذا بسبب تأثير الفاقد في الاحتكاك. وكانت القيمة الكلية للفاقد في الاحتكاك ٠,١٢٢، ٠,١٢١ ، ٠,١١٨ بار لخطوط التنيقط ١، ٣٠ و٦٠ (خط التنقيط الاول-الاوسط-الأخير) علي الترتيب. هذا بسبب كبر كمية المياة المارة خلال خط النقاطات ١ وتقل تدريجيا كلما بعد خط النقاطات عن مصدر المياه.
٢. لوحظ تغير طفيف في التصرفات لمداخل خطوط النقاطات على طول المشعب وكانت من ٣٠٤,٤ الي ٢٩١,٩ لتر/ساعة. وكذلك وجد تغير بسيط في الضغط لمداخل خطوط النقاطات وكانت من ١,٠٤ بار (بداية الخط المشعب عند خط النقاطات رقم ١) الي ٠,٩٦ بار (نهاية الخط المشعب عند خط النقاطات رقم ٦٠). الزيادة في الضغط عند بداية الخط المشعب كانت بسبب زيادة الفاقد في الاحتكاك والراجع لتدفق كمية كبيرة من المياه في مدخل الخط المشعب.

تم أختبار صحة النموذج الرياضي لكل من تصرف النقاطات علي خطوط النقاطات (١، ٣٠ و٦٠) نسبة التغير في التصرف (Q_{VAR}) ونسبة التغير في الضغط (H_{VAR}). و معامل توزيع المياه (U_C).

١. القيم المتنبأ بها والقيم المقاسة لتصرف ١٤٠ نقاط علي كل خط تنقيط علي خطوط النقاطات (١، ٣٠ و٦٠) كانت نسبة الانحراف لها ١,٢٤، ١,٦٥ و٨,٣٪ علي الترتيب. هذا يعني أن النموذج الرياضي قادرعلي التنبؤ بتصرف أي نقاط علي أي خط من خطوط النقاطات وبدقة عالية.
٢- القيم المتنبأ بها والقيم المحسوبة من نتائج التجارب الحقلية لنسبة التغير في التصرف والضغط و معامل توزيع المياه (U_C) لعدد ٦٠ خط تنقيط كانت نسبة الانحراف لها ١,٨، ٢,١ و٢,٦٪ علي الترتيب. هذا يعني أن القيم المتنبأ قريبة جدا من القيم المحسوبة من نتائج التجارب الحقلية.
٣. القيم المتنبأ بها عن طريق النموذج الرياضي بالكمبيوتر لأطوال اجزاء الخط المشعب (One side lateral) ١٠,٥، ٧,٥، ٧,٥ و١٨,٧٥ متر عند الاقطار ٥٠، ٦٣، ٧٥ ، ٩٠ مم علي الترتيب للوصول الي (U_C) يساوي ٩٥٪.

تم أختبار حساسية النموذج الرياضي لكل من التصرف والضاغط عند كل نقاط وعند كل نقطة أتصال بين كل خط النقاطات والخط المشعب تحت الظروف المختلفة من الميول، وأطوال وأقطار خطوط النقاطات، والوصلات الداخلية للنقاطات وأنواع مختلفة من النقاطات.

١. تزداد قيمة معامل توزيع المياه (U_C) بزيادة طول خطوط النقاطات لحد معين بعدها قيمة (U_C) تميل للانخفاض، في حالة النقاط (تصرف ٢,٠٨ لتر/س) ومسافات ١ متر بين النقاطات. كما لوحظ تأثير لقطر خط النقاطات والميل علي قيمة (U_C) لطول خط النقاطات ٤٠ متر. هذا بسبب صغر التصرف الكلي المار بخط النقاطات. ولنفس قطر خط النقاطات قيمة (U_C) لا تتأثر في حالة الميل صفر والميل لاعلي (Uphill) وحتي ٥٪. أما بالنسبة في حالة الميل لاسفل لوحظ تحسن واضح في قيمة (U_C) وكانت تتراوح من ٠,٩٦-٠,٩٨ لاقطار خطوط النقاطات ١٦ و ١٨ مم مع أطوال خطوط النقاطات أقل من ٢٥٠ متر. بينما لوحظ انخفاض في قيمة (U_C) لقطر خط النقاطات ١٣ مم بعد طول ١٦٠ متر. وذلك راجع الي أن الميل لاسفل (Downhill) يكسب طاقة ضغط تعادل الفاقد في الاحتكاك.
٢. قيمة (U_C) تميل للانخفاض بزيادة قيمة ثابت النقاط (Emitter exponent). كما تقل قيمة(U_C) بوضوح من ٩٦ الي ٨٤٪ بتغير ميل خط النقاطات٥٪ (Downhill) الي ٥٪ (Uphill) عند ثابت لنقاط المساوي للواحد. لأن مجموعة النقاطات تمثل السريان الرقائقي والمتأثرة بتغير الضاغط بسبب الميول.
٣. معدل أمخفاض (U_C) يزداد بوضوح من ٣,٥، ٩,٢، ١٥,٧٪ مع زيادة ثابت النقاط بتغير الميل من -٥ ، صفر ،٥٪ علي الترتيب. في حالة ثابت النقاط قريبا من ٠,١ لا يوجد تأثير للميل علي معامل توزيع المياه وذلك بسبب أن مجموعة النقاطات تمثل تعويض الضغط. بينما مجموعة النقاطات ذات ثابت تصرف مساويا ٠,٥ تتغير قيمة (U_C) من ٠,٩٧ الي ٠,٩٠.
٤. تزداد قيمة (U_C) من ٩٢ الي ٩٩٪ بزيادة طول خط النقاطات وحتي ٨٠ متر لكل الوصلات الداخلية للنقاطات (Small-Medium-Large) علي الجانب الاخر بزيادة طول خط النقاطات عن ٨٠ متر، تنخفض قيمة (U_C) بوضوح وهذا راجع الي زيادة مساحة مقطع خط النقاطات يؤدي الي انخفاض الفاقد في الاحتكاك. قيمة (U_C) في حالة (In-line emitter) اقل تأثرا عن النقاط (On-line emitter)
٥. اوضحت النتائج ان النموذج الرياضي قادر علي التنبؤ بصورة جيدة وبدقة عالية في أجراء التصميم الهيدروليكي لكل من خط النقاطات والخط المشعب للقطعة الفرعية للري بالتنقيط. كما أنه قابل للتطبيق عمليا في التصميم لاي قطعة أرض بنسبة خطأ ضئيل