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A DEVELOPED OF DIMENSIONAL MODEL TO ESTIMATE FRICTION LOSSES IN ON-LINE DRIP IRRIGATION LATERALS

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ABSTRACT

The study presents a developed prediction model for estimating friction losses in drip irrigation laterals based on dimensional analysis. Drip irrigation laterals with on-line barb emitters placed at different spacing. The parameters affecting the variation in friction losses in laterals were defined as dimensionless terms. The experimental work conducted at Irrigation Testing National Laboratory, AEnRI, Egypt. The Egyptian standard methods of emitters testing were used; five locally manufactured types of emitters were subjected to tests. The developed mathematical model was:

$$H_f = 0.1467\, Q^{2.018} L^{27.546} D^{-4.415} dL^{-27.206} d^{0.03}$$

Where H_f is the friction loss in a unit length of lateral (m), Q is the lateral flow rate in L.h^{-1}., D is the lateral interior diameter (m), d is the emitter diameter (m), dL is the emitter spacing (m), and L is the lateral length (m).

The developed model is valid for barb emitter type; up to 250 m of lateral length; (13:20 mm) lateral interior diameter; (0.75:1 m) emitter spacing; (2.5:4.5 mm) emitter diameter; and emitter' average flow rate of (2:8 L.h^{-1}). Results of the developed model had a correlation factor of about 0.985 with measured data. Thus, the developed model may be effectively used to determine friction losses in drip irrigation laterals. Statistically significant differences were observed. The study showed that there are needs of more studies based on techniques considering other parameters such as water temperature.

INTRODUCTION

One of main aspects of drip irrigation systems is the hydraulic design of laterals which distribute irrigation water throughout the field.

Theoretically, it is assumed that water distribution along the lateral lines could be equity achieved but, under field conditions deficiency had been found which may be caused by operating pressure, water temperature differences, emitter manufacturing coefficient, emitter clogging and pressure variations caused by slope and friction losses (Demir, *et al.* 2004; Howell and Barinas, 1980)

Generally, laterals made of Poly Ethylene which considered as a smooth pipe, hence, the well known formulas as Darcy-Weisbach and Hazen-Williams could be used to determine friction losses along the lateral as follow (*El-Fetiany et al., 2000, Warrick and Yitayew 1988, Amer and Gomaa, 2003* and *Amer, 2005*):

Darcy- Weisbach equation:

$$H_f = f \frac{L}{D} \cdot \frac{V^2}{2g}$$

Where H_f is the friction loss of the pipe (m), L the pipe length (m), D the inside diameter of pipe, V velocity (m.s^{-1}), g the gravitational acceleration and f the friction coefficient. The friction coefficient could be obtained from many source as empirical tables and namo-graphs; *Kang and Nishiyama 1996*, recommended the used of the Blasuis equation for estimation of friction coefficient of smooth pipes at turbulent flow conditions which is:

$$f = 0.3164\, R_e^{-0.25} \qquad (4000 \leq Re \leq 100000)$$

Where: $R_e = \frac{V\,D}{\mu}$ is the Reynolds number,μ the kinematic viscosity of water.

Hazen-Williams equation:

$$H_f = 6.84 \frac{L}{C^{1.852}} \frac{V^{1.852}}{D^{1.167}}$$

Where: H_f in (m), L in (m), D in (m) and V in (m.s^{-1}) and **C** is the roughness coefficient called Hazen-Williams coefficient. On other hand, *Warrick and Yitayew 1988* stated that Darcy-Weisbach model is more suitable for small lateral diameters than Hazen-Williams model which is more precisely when using large diameters.

Hegazi, 1994, Sharaf, *et al.*, 1996, reported that the roughness coefficient can be taken as in arrange of 100-130 for drip irrigation pipes.

Hanafy, 1995 developed total head curve technique based on poly-plot concept for polyethylene laterals with 13.1, 15.6 and 17 mm inside diameters.

Abdel-Aal, 2000 studied the effect of inlet operating pressure under different lateral diameters and lengths on emission uniformity, emitter flow variation, potential application efficiency of low quarter, friction head losses. The study was carried out on pea production using two polyethylene lateral diameters, three lengths of lateral lines and three inlet operating pressures. Results recommended that using of Darsy-Weisbach formula is the appropriate method for calculating the pressure losses due to friction. In addition it is recommended to use submain with 18 mm diameter and 30 m length to gain distribution uniformity as high as 96.6%.

Generally, in the design of drip irrigation systems, friction looses are found based on the assumption that the flow rates of emitters are the same along the lateral and flow is turbulent *(Bratts and Wu, 1979)*. Not only the drip laterals are smooth pipes with turbulent flow and they are multiple outlet pipes. Thus, the total friction loss is equal to the sum of losses between the outlets; therefore the friction loss along the lateral line could be calculated by multiplying the losses between the outlets by outlets number.

Valiantzas, 2002 used a correction factor to modify the traditional approach of calculating the friction head loss along laterals as follows:

$$H_f(L) = F \cdot H_{fo}$$

Where

$$F = \frac{1}{m+1}\left[1+\left(\frac{1}{2N}\right)^{m+1} - \left(\frac{1}{2N}\right)^{m-1}\right]$$

Where: ***$H_f(L)$***; total friction head loss along the total length of the lateral, ***F*** friction head loss correction coefficient , ***H_{fo}*** friction head loss calculated using traditional method based on Darcy-Weisbach or Hazen-Williams extended to Scopy formula, **m** velocity exponent in used formula, ***n***; the diameter exponent and ***N*** the number of outlets.

Zella and Kettab 2002 used the control volumes method (CVM) for the hydraulic analysis of the laterals microirrigation; they concluded that the developed model has the advantage to be simple, fast, precise and allow extension to large microirrigation network. The CVM method depends on both of mass and energy conservation principles. Ismail, *et al.* 2001 developed an interactive computer aided model to simplify the design and planning of trickle irrigation systems based on Darcy-Weisbach model in calculating friction losses along lateral lines.

Amer and Bralts, 2005 used a developed model in order to calculate the lateral or submain line with multiple outlets whose flow is non-uniform. The developed model is based on a combination of Darcy-Weisbach and Balsuis models.

$$\Delta H_\lambda = \frac{K_1}{2.75}\frac{\alpha Q^{1.75} L}{D^{4.75}}\left(1-\left(1-\frac{\lambda}{L}\right)^{2.75}\right)$$

Where; ΔH_λ is friction loss head (m) at a length λ is measured from inlet, α is equivalent barb coefficient, K_1 is friction factor which depends on water temperature, viscosity and protrusion, Q is inlet flow rate ($m^3.s^{-1}$), L lateral length (m) and D is lateral inside diameter (m).

Dimensional analysis is a useful tool for developing predicted equations for various physical systems; it reduces the physical quantities pertinent to a systemic dimensional group *Demir, et al. 2004*.

The objective of this study was to develop a prediction model for estimating friction losses of the drip irrigation laterals under on-line emitters conditions based on dimensionless analysis technique.

MATERALS AND METHODS

The study was carried out using the apparatus built in the National Irrigation Laboratory of Agricultural Engineering Research Institute. The apparatus equipped with flow rate controls, digital flowmeters, pressure regulators, digital pressure meters and water temperature readout.

Different drip irrigation pipes with different emitters spacing were used (Table 1), the friction losses were measured according to international and Egyptian standards, at water temperature was 20°C (±2 ° C).

Table (1): Data specifications of tested emitters.

Item	Emitter type*				
	1	2	3	4	5
Emitter diameter (mm)	2.6	3.0	3.5	3.5	4.1
Average flow rate ($L.h^{-1}$)	2	2	4	6	8
Lateral diameter (mm)	14, 16, 18				
Emitter spacing (m)	0.75, 0.80, 0.90,1.0				

*** All emitter types are point source (barb) type.**

The application of the dimensional analysis to findout the laterals friction losses in with on-line emitters. Table (2) summarizes the quantitative parameters affecting the efficiency of hydraulic drip irrigation system and their symbols. Figure (1) shows the dimensions of on-line emitter.

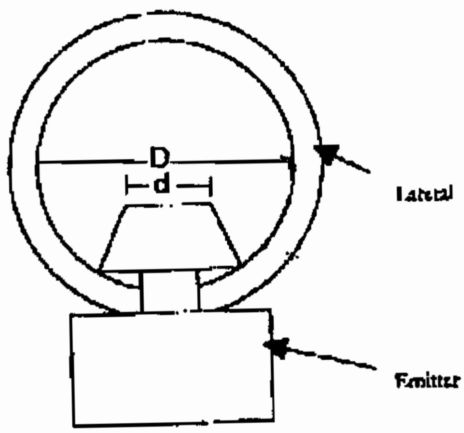

Figure (1): Dimensions of on-line emitter

The previous quantities are the most pertinent, non-redundant quantities can affect on the lateral friction losses. From Table (2) seven dimensionless π groups had been observed, as shown in Table (3).

Table (2): Variables affecting friction losses in surface drip irrigation system.

Type of variable	Variable	Symbol	Unit	Dimensions
Dependent	Friction head loss	H_f	m	L
Independent	Lateral diameter	D	mm	L
	Emitter diameter	d	mm	L
	Lateral length	L	m	L
	Emitter spacing	dL	m	L
	Gravitational	g	ms^{-2}	LT^{-2}
	Flow velocity	V	ms^{-1}	LT^{-1}
	Viscosity of water	μ	m^2s^{-1}	L^2T^{-1}

Table (3): Dimensionless groups and their indications.

Dimensionless group	Indications
$\frac{H_f}{L}$ (π_1)	Friction loss in a unit length of lateral.
$\frac{V \cdot D}{\mu}$ (π_2)	Reynolds number.
$\frac{V^2}{g \cdot D}$ (π_3)	Froude number.
$\frac{dL}{L}$ (π_4)	Ratio of emitter spacing to lateral length.
$\frac{d}{dL}$ (π_5)	Ratio of emitter diameter to emitter spacing.
$\frac{d}{D}$ (π_6)	Ratio of emitter diameter to lateral diameter.
$\frac{D}{L}$ (π_7)	Ratio of lateral diameter to lateral length.

While Reynolds number expresses the fluid characterization in dimensionless term, as the ratio of inertia force to viscous forces, Froude number expresses the ratio of inertia force to gravity forces; moreover, the shrink ratio expresses the ratio of emitter diameter to pipe diameter.

The dependent term π friction losses per unit length can be expressed as a proportional function of independent groups as follows:

$$\frac{H_f}{L} = f\left(\frac{V.D}{\mu}, \frac{V^2}{g.D}, \frac{dL}{L}, \frac{d}{dL}, \frac{d}{D}, \frac{D}{L}\right)$$

A non-linear procedure was performed to laboratory in order to get the regression model using SPSS® program.

RESULTS AND DISCUSSION

During laboratory tests, water temperature was 20°C (± 2°C), it was kept constant, therefore the kinematic viscosity μ didn't vary. Since the kinematic viscosity didn't vary, just velocity V and lateral diameter D varying in Reynolds number and velocity and diameter found in Froude number, hence Reynolds number can be eliminated from the equation (*Demir et al., 2004*). Thus the lateral friction losses per unit length will be a function of all other terms as follows:

The non-linear results in the following prediction equation:

$$\frac{H_f}{L}=\left(\frac{V^2}{g.D}\right)^{1.009}\left(\frac{dL}{L}\right)^{0.004}\left(\frac{d}{dL}\right)^{27.21}\left(\frac{d}{D}\right)^{-27.18}\left(\frac{D}{L}\right)^{-26.55}$$

Where H_f is the friction loss in a unit length of lateral (m), V is velocity (m.s^{-1}), D is lateral interior diameter (m), d is emitter diameter (m), dL is emitter spacing (m), and L is lateral length (m).

Results of regression analysis are tabulated as in Table (4), it revealed power of the investigated terms, which are significant at 95% probability. The developed model can be formed in the following equation:

$$H_f = 0.09V^{2.018}L^{27.546}D^{-0.379}dL^{-27.206}d^{0.03}$$

On other hand, the friction loss of a unit length of lateral can be calculated using the flow rate as:

$$H_f = 0.1467\,Q^{2.018}L^{27.546}D^{-4.415}dL^{-27.206}d^{0.03}$$

Where Q is the lateral flow rate, L.h^{-1}.

The prediction model was verified against another set of experiments which not used in model forming. Figure (2) represented the relation between model and measured data in 1:1 scale. The model data were calculated at the same flow rates, lateral's diameter and length, and emitter spacing and diameters conditions of measured data. The developed model used for barb emitter type; up to 250 m of lateral length; (13t to20 mm) lateral interior diameter; (0.75 to 1 m) emitter spacing; (2.5:4.5 mm) emitter diameter; and emitter' average flow rate of (2 to 8 L.h^{-1}).

Table (4): Results of non-linear regressions analysis

	Power	Standard Error	R^2%
$\frac{V^2}{g \cdot D}$	1.009	1.65E-2	98.24
$\frac{dL}{L}$	0.004	1.72E-2	97.75
$\frac{d}{dL}$	27.21	1.12E-3	97.61
$\frac{d}{D}$	-27.18	8.85E-3	95.14
$\frac{D}{L}$	-26.55	1.98E-4	92.11

Figure (2) showed a good correlation. Correlation coefficient of model and measured data was 0.985., this mean that the developed model could be used precisely in the mentioned ranges.

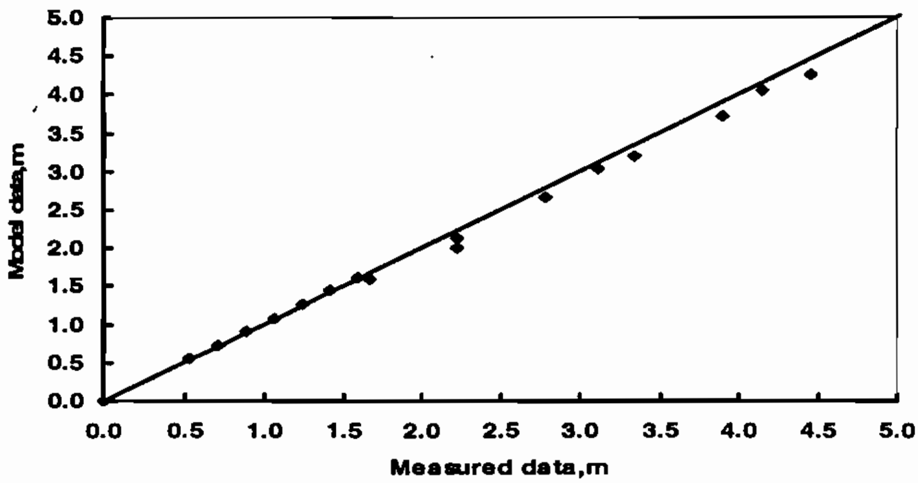

Figure (2): Measured data vs. developed model.

One of the differences between the obtained model and *Demir's, et al. 2004* model; that the obtained model is suitable for on-line emitter types while the other is used for in-line emitter type. On other hand, *Demir, et al. 2004* used dimensionless group which characterize the in-line emitter, the obtained model used dimensionless groups 4 to 7 in Table (3) to characterize the operating conditions as well as manufacturing properties of both of lateral and emitter.

One of the model finding is the capability of comparing the head losses of using different on-line drippers.

Figure (3) represented the comparison of five locally emitter types at the condition of discharge (2 $L.h^{-1}$), emitter spacing (0.75 m), lateral interior diameter (0.032 m) and lateral length (50 m). The comparison showed the differences between emitter types.

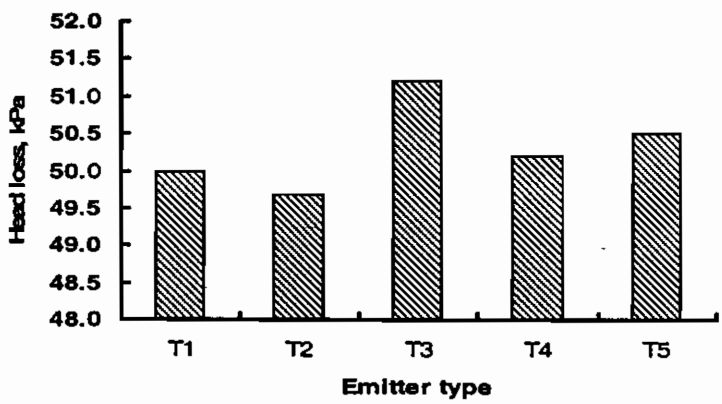

Figure (3): Comparison of five emitter types.

Statistically, significant differences at 95% significance level were found as shown in table (5). The differences were found due to the differences in emitter's material as well as the variations founded in manufacture's coefficient of each emitter type.

Table (5): statistical analysis of emitter types.

LSD = 0.002 at 0.05 significance level	
Emitter	**Mean head loss, kPa**
T1	50a
T2	49.7b
T3	51.2c
T4	50.2c
T5	50.5d

CONCLUSION

From the study it can be concluded that:

1- The developed model is a good estimator of friction loss along drip surface irrigation lateral for different on-line barb emitters.
2- The developed model can be used to calculate the friction loss for design purpose at different spacing in consider with soil infiltration value.
3- It is believed that more sophisticated model that includes the effect of water temperature and other types of emitters are needed.

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تطوير نموذج رياضي لتقدير فاقد الاحتكاك في الخطوط الفرعيـــة لنظـــام الـــري بالتنقيط

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استخدم في هذه الدراسة أسلوب التحليل اللابعدي لاستنباط نموذج رياضـــي للتنبــؤ بفاقــد الاحتكاك داخل الخطوط الفرعية لنظم الري بالتنقيط السطحي. وقد أجريت هذه الدراسة في المعمل القومي للري بمعيد بحوث الهندسة الزراعية – الدقي، مستخدما ظروف تشغيلية مختلفة مثل أقطار مختلفة من الأنابيب الفرعية وكذلك أنواع مختلفة من النقاطات والتي تم وضـــعها علـــى مـــسافات مختلفة. وقد استخدمت المجموعات اللا بعدية للتعبير عن المتغيرات التي تؤثر في فاقد الاحتكـــاك داخل الأنابيب الفرعية وقد استنتجت العلاقة التالية من الدراسة:

$$H_f = 0.1467\, Q^{2.018} L^{27.546} D^{-4.415} dL^{-27.206} d^{0.03}$$

حيث H_f فاقد الاحتكاك في الخط (متر)، Q تصرف الخط (لتر/س)، L طول الخط (متر)، D القطر الداخلي للخط (متر)، dL المسافة بين المنقطات (متر)، d قطر المنقط.

أظهر النموذج المستنبط عند مقارنة نتائجه بالنتائج الحقلية دقة عالية فـــي اســـتنتاج فاقــد الاحتكاك خلال الأنابيب الفرعية حتى طول ٢٥٠ متر وأقطار داخلية في المـــدى (١٣: ٢٠) مـــم، ومسافات بينية في المدى(٠,٧٥ : ١,٠٠) م ،قطر نقاط في المدى (٢,٥ : ٤,٥) مم ومتوسط معدل تصرف للنقاط في المدى (٢:٨) لتر/س.

وقد اتبع الكود المصري في اختبار خمس أنواع من المنقطات محلية الصنع وأظهر التحليل الإحصائي وجود اختلافات معنوية بينها وترجع تلك الاختلافات إلى نوعية مـــادة النقـــاط وكـــذلك الاختلافات الموجودة في معامل التصنيع لكل نوع.

توصى الدراسة بإمكانية استخدام المعادلة المستنبطة وذلك لـــسرعة تحديـــد الفقـــد نتيجـــة الاحتكاك داخل خطوط الري بالتنقيط في حدود المتغيرات تحت الدراسة.