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A HYDRAULIC STUDY OF TRICKLE IRRIGATION

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دراسة هيدروليكية لنظام الرى بالتنقيط

خلاصة

تتخدم أنابيب البولى ايثيلين بكثرة فى نظام الرى بالتنقيط، تهدف هذه الدراسة الى ايجاد معامل الأحتكاك لهذا النوع من الأنابيب فقد أجريت دراسة حقلية على خطين من الأنابيب طول كل منهما حوالى ٢٤٠ متر أحدهما بقطر ١٨٫٥ مم والآخر يتكون من جزئين أحدهما بقطر ٢١٫٥ مم والآخر بقطر ١٧ مم ٠

تم مقارنة معامل الأحتكاك المقاس عن طريق معادلة دارسى ـ فيسباخ بنظيره المحسوب عن طريق بعض المعادلات التطبيقية وبناء على هذه المقارنة عدلت معادلة بلاسيس لتناسب هذا النوع من الأنابيب، كما أستنتجت بعض المعادلات لايجاد العلاقة بين رقم رينولدز ومعامل الأحتكاك وذلك بناء على القياسات الحقلية عن طريق التحليل الأحصائى ٠

شملت الدراسة أيضا ايجاد العلاقة بين تصرف المنقط والضغط الواقع عليه ٠

ABSTRACT

Polyethylene pipes are widely used in the trickle irrigation system. The main objective of this research work is to determine friction factors for this type of pipes.

A field study was carried out on two trickle irrigation laterals each of which was about 240 m in length . One line had 18.5 mm inside diameter, the other consisted of two parts, the first was 21.5 mm inside diameter and the other was 17 mm inside diameter.

The measured friction factor was compared by the corresponding friction factors given by conventional friction formulae. Blasius equation has to be modified to cope with the measured factors, and predicted equations are presented.

The relationship between the discharge of the orifice type emitter and the pressure exerted on it,is given.

INTRODUCTION

The equation of computing an accurate friction factor in Darcy-Weisbach formula is of a great importance. Blasius proposed a simple equation for estimating the friction loss factor for smooth pipe. This equation is a function only of the Reynolds number. It was found to work well for small diameter plastic pipes when Reynolds number is less than 10^5 (8). Design limitation on velocity in trickle irrigation laterals (1.5m/sec) gives Blusius equation reasonably accurate estimation of friction factor for smaller plastic pipe smaller than 80mm.

The Colebrook White (C-W) equation is the basis for the well known friction factor (Moody diagram). Several publictions have given the solution of the C-W equation on mini computers. There are also a numerous explicit solution on the C-W equation (9).

The Hazen Williams empirical equation is widely used for the trickle irrigation system because of its simlicity, but it has no correction for the viscosity changes.

The main objectives of this research work are : (1) to obtain friction factor for polythene trickle irrigation laterals; (2) to compare different fricition formulae in determining the friction factor ; (3) to determine an accurate equation for predicting friction factor in small polyethylene pipe and (4) to exhibit the relationship between emitter discharge and the pressure exerted on it.

FRICTION EQUATIONS FOR DRIP IRRIGATION LINE

Darcy-Weisbach Equation:

The drip irrigation lines made of polyethylene are usually considered as smooth pipe. The Darcy-Weisbach equation is used to determine the friction head loss in the pipe.

$$H_f = 6.377\ f\ L\ D^{-5}\ Q^2 \quad \text{..............................(1)}$$

in which;

H_f = friction head loss in m;

L = length of pipe in m ;

D = diameter of pipe in mm;

Q = flow rate in Lit./hr.; and

f = friciton factor.

The equation incorporates the acceleration of gravity 9.81 m/sec^2.

For Laminar flow the friction factor is given by:

$$f = \frac{64}{R_e} \quad (R_e<2000)\dots\dots(2)$$

and for transition region the friction factor could be approximated by:

$$f = 3.42 * 10^{-5} * R_e^{0.85} \quad (2000\leq R_e\leq 4000)\dots\dots(3)$$

For smooth turbulent flow which usually occurs in trickle irrigation system, the friction factor (f) could be characterized by:

Blasius equation:

$$f = 0.316\ R_e^{-0.25} \quad (4000\leq R_e\leq 10^5)\dots\dots(4)$$

or Colebrook-White equation:

The C-W equation is used to determine the friction factor (f) it has the following implicit form:

$$\frac{1}{\sqrt{f}} = -2\ \mathrm{Log}\left(\frac{K}{3.76D} + \frac{2.54}{R_e\sqrt{f}}\right)\dots\dots(5)$$

in which;

f = friction factor;

D = inside diameter of pipe;

R_e= Reynolds number; and

K = relative pipe roughness.

Barr (2) provided an explicit solution for the Colebrook-White equatiion in the following form:

$$\frac{1}{\sqrt{f}} = -2\ \mathrm{Log}\left(\frac{K}{3.7D} + \frac{5.2}{R_e}\right)\dots\dots(6)$$

The estimated values of relative roughness for polyethylene pipes are given in Table (1).

Hazen-Williams Emperical Equation:

This equation is widely used for the trickle system design (7) because of its simplicity, but it has no correction for viscosity changes, it is given by :

$$H_f = 0.628\ L\ D^{-4.865}\ [100\ Q/C\ ]^{1.852} \qquad (7)$$

in which;

H_f = friction head loss in m;

L = length of pipe in mm;

D = diameter of pipe in mm;

Q = flow rate in Lit./hr., and

C is the pipe roughness coefficient , it varies between 130 and 150 depending on Re in terms of the friction factor.

Many pipe manufactures recommend a maximum velocity of 1.5 m/sec. in plastic pipe and at this velocity the value of C that compares best with the Blasius equation will depend on the pipe diameter as follows (5) :

C = 130 for 14 to 15 mm pipe
C = 140 for 18 to 19 mm pipe; and
C = 150 for 25 to 27 mm pipe.

The friction factor (f) from Hazen Williams equation is given by:

$$f = \frac{1862}{C^{1.852}\ D_{mm}^{0.18}\ Re^{0.148}} \qquad (8)$$

FIELD WORK

Two available polythylene trickle irrigation laterals were selected. The two lines were approximately 240 m.in length. The first lateral was 18.5 mm inside diameter and the second lateral consisted of two parts the first one had 21.5 mm inside diameter in a length of about 200 m. and the second part had 17.0 m. inside diameter. The emitters spaced at about 2.5 m. in average. Survey was carried out to determine the levels, and the distance between every two successive emitters for both the two laterals.

The pressure exerted on every emitter was measured by a pressure dial gauge with an accuracy of 0.5 psi. Water discharge from the emitter was measured by using stop watch and container.

For measuring the friction head loss in every lateral, emitters were closed and the end of lateral was opened. Water discharge was measured using different means, flow meter, propeller meter and by using stop watch and container (85 litres) which was found to be more accurate. The pressure was measured at selected emitter locations. Water temperature was measured at the begining and end of the lateral for every reading. The corresponding kinetic viscosity was obtained according to the mean value of water temperature.

The data were carefully collected and volume measurements were made over long periods to minimize the flow rate errors.

RESULTS AND ANALYSES

Emitter connection loss values for various size of barbs and inside diameter of laterals are given in (4) . Emitters under investigation were of small size, the emitter connection loss is given by the following equation:

$$CL = 0.034\ D^{-0.2018} \qquad (9)$$

in which, CL is the equivalent length in feet and D is the pipe diameter in inch. This equation will give an equivalent length of about 2 cm. per emitter in calculating the pipe friction in lateral.

Height of roughness (K) for pipes under consideration could estimated by linear interpolation Table (1). According to the table, two values could be used from two points of view.

The different values of friction factors using the C-W equation are given in Fig. (1a) for 21.5 mm. inside diameter lateral and Fig. (1b) for 17.0 mm. inside diameter lateral.

Fig. (2a) exhibits the relationships between friction factor and Reynolds number for the Hazen-Williams, Blasius, Colebrook White (K=0.012mm) and the measured values. The figure also demonstrates the modified and predicted equations for 21.5 mm inside diameter lateral. Fig. (2b) gives the same relationships as in Fig. (2a) except in the case of C-W equation the estimated value of roughness height (K) is 0.065 mm.

Fig. (3a) and Fig. (3b) provide the same relationships as in Fig. (2a) and Fig. (2b), for K = 0.014 and K=0.062 mm respectively, in the case of 18.5 mm inside diameter lateral.

Friction factors and predicted equations for 17.0 mm inside diameter lateral are given in Fig.(4a) and Fig.(4b) for K = 0.015 mm and K = 0.06 mm respectively.

The relationship between Reynolds number and the friction coefficient in smooth turbulent flow could be written in the form:

$$f = a\, R_e^{b} \qquad (10)$$

in case of Blasius equation the value of a = 0.316 and the value of b = -0.25.

Modified Blasius Equations:

Blasius equation has to be modified to deal with the actual field measurements. The value of (b) was kept constant at -0.25 and the mean value of (a) was calculated according to the field measurments. The following equations are given:

$$f = \frac{0.335}{R_e^{0.25}} \qquad \text{for } D = 21.5 \text{ mm} \qquad (11)$$

$$f = \frac{0.339}{R_e^{0.25}} \qquad \text{for } D = 18.5 \text{ mm} \qquad (12)$$

$$f = \frac{0.342}{R_e^{0.25}} \qquad \text{for } D = 17.0 \text{ mm} \qquad (13)$$

Predicted Equations:

Based on the field measurements of friction factor and the corresponding Reynolds number, the data were analysed by runing SAS, (6) a nonlinear regression procedure in the form of power function as given by Blasius, the similer equations are given as follows:

$$f = \frac{0.245}{R_e^{0.22}} \qquad \text{for } D = 21.5 \text{ mm} \qquad (14)$$

$$f = \frac{1.545}{R_e^{0.399}} \qquad \text{for } D = 18.5 \text{ mm} \qquad (15)$$

$$f = \frac{0.160}{Re^{0.178}} \quad \text{for } D = 17.0 \text{ mm} \qquad (16)$$

$$f = \frac{0.553}{Re^{0.298}} \quad \text{for the three pipes} \qquad (17)$$

Emitter Discharge:

The orifice type emitters are commonly used in trickle irrigation. The two lateral lines one of which was 21.5mm in diameter and the other was 18.5mm in diameter. The flow cross section of emitter hole was 4.43 mm^2 and the flow cross section of the emitter was 3.55 mm^2, diameters were measured by micrometer.

The flow in an orifice emitter is considered a flow through a small opening. For fully turbulent flow regime, the flow rate is expressed as (5):

$$q = 3.6\, A\, C_o \sqrt{2gH} \qquad (18)$$

in which ; q is the emitter flow rate in lit./hr., A is an orifice area in mm^2 , C_o is the orifice coefficient usually 0.6; g is the acceleration of gravity and H is the pressure head.

However the emitter discharge could be written in the form:

$$q = C_1 H^n \qquad (19)$$

where the constant n depends on the flow regime, as the flow regime approaches Laminar for which n = 0.7-0.8. For Laminar flow ($Re < 2000$) n = 1.0 and for ($3000 \le Re \le 10^5$) n = 0.57 and for fully turbulent flow ($Re > 10^5$) n = 0.5 (5).

Equation (19) could be written in the form:

$$q = C_2 P^n \qquad (20)$$

in which q is the flow rate in lit./hr. and P is the pressure in kg/cm^2 exerted on emitter.

For 21.5 Lateral Equation (20) is:

$$q = 104.1\, P^{0.55} \qquad (21)$$

and for 18.5 mm lateral the equation is :

$$q = 88.2\ p^{0.61} \quad \text{.......................................(22)}$$

The value of n ranges between 0.55 and 0.61, the maximum value of $R_e = 5.78*10^4$.

Fig. (5a) gives the relationship between discharge and pressure for 21.5mm latral and Fig.(5b) exhibits the same relationship for 18.5mm lateral.

Considering a fully opened emitter cross section ($3.55\ mm^2$) equations (21) and (22) could be wrttien as :

$$q = 83.42\ p^{0.55} \quad \text{for 21.5 mm lateral...................(23)}$$

and

$$q = 70.68\ p^{0.61} \quad \text{for 18.5 mm lateral...................(24)}$$

CONCLUSIONS

Reynolds number greater than 10^5 is seldom to occur in trickle irrigation laterals because the mean velocities within the pipes are rare to be greater than 4.0 m/sec. Maximum value of Reynolds number for 17.0 mm inside diameter pipe was $58.9 * 10^3$ with a corresponding maximum mean velocity of 2.59 m/sec. at the recorded temperature.

On the other hand, the minimum value of Reynolds number for pipes under investigation was $12.3 * 10^3$ with the corresponding minimum mean velocity of 0.5 m/sec. Value of $R_e = 10^5$ requires a value of mean velocity of 4.71 m/sec, 4.32m/sec and 3.72 m/sec at 30° C for inside pipe diameter of 17.0 mm, 18.5 mm and 21.5 mm respectively. These values of velocities increases with the decreasing value of water tempreture.

Blasius equation within the practical range of Reynolds number ($12 * 10^3 \leq R_e \leq 60 * 10^3$) for trickle irrigation laterals is more accurate in calculating the friction factor than the Hazen Williams equation or Colebrook White equation. In addition, the C-W equation depends on the accurate estimation of the relative roughness.

The calculated roughness coefficients, using Blasius equation are usually less than the corresponding measured factors given by Darcy-Weisbach equation. Blasius equation has been modified to deal with every pipe diameter, equations are given.

Based on field measurments and statistical analyses, predicted equations for calculating the friction factors in terms of Reynolds number are presented.

The power relationship between the discharge of the orifice type emitter and pressure is given. It has an exponent value varies between 0.55 and 0.61

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NOTATION

The following symbols are used in this paper:

A = orifice area;
C = pipe roughness coefficient;
CL= emitter connection loss;
C_o= orifice coefficient;
C_1= constant;
C_2= constant;
D = pipe diameter;
F = statistcal parameter;

H = pressure head;
H_f = friction head loss;
K = pipe relative roughness;
p = pressure;
Q = lateral flow rate;
q = emitter flow rate;
R^2 = multiple correlation coefficient;
Re = Reynolds number; and
T = statistical parameter.

Fig (1a) Application of C-W Equation for 21.5 mm Polyethylene Pipe

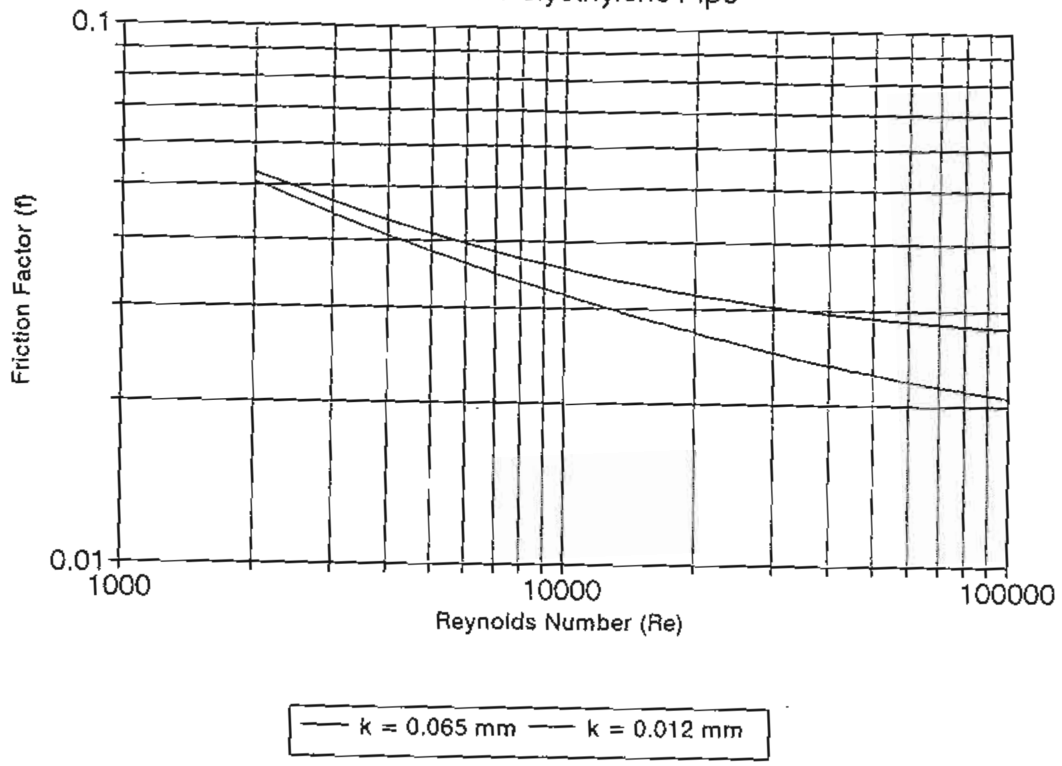


Fig (1b) Application of C-W Equation for 17.0 mm Polyethylene Pipe

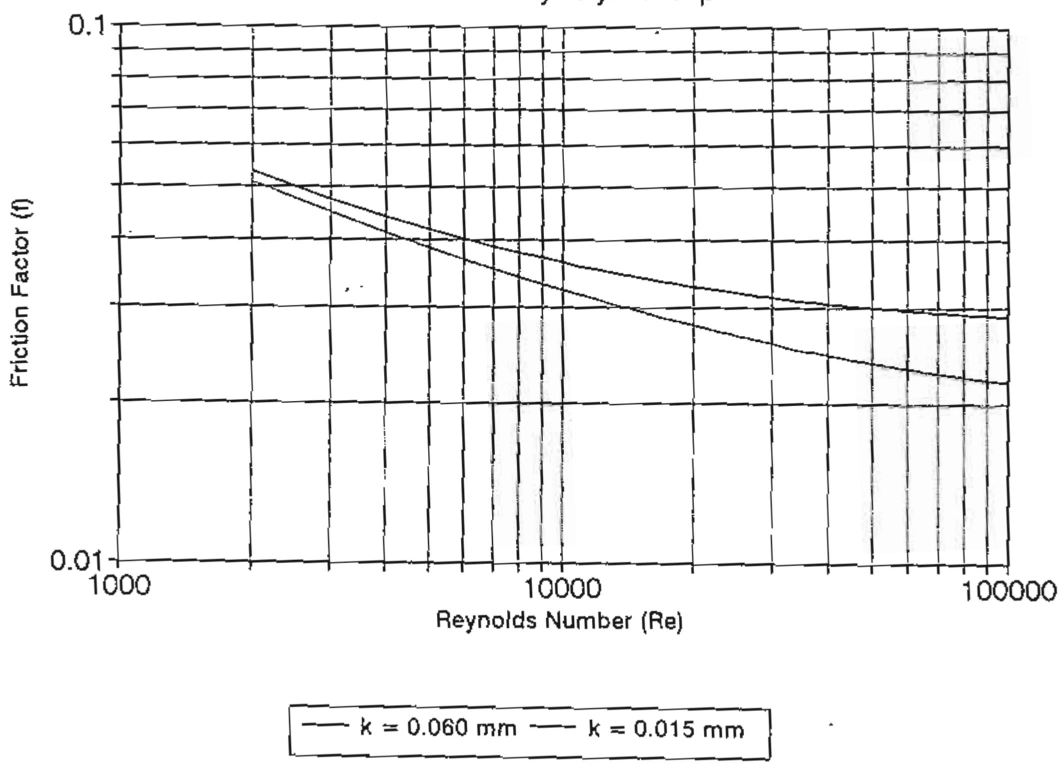
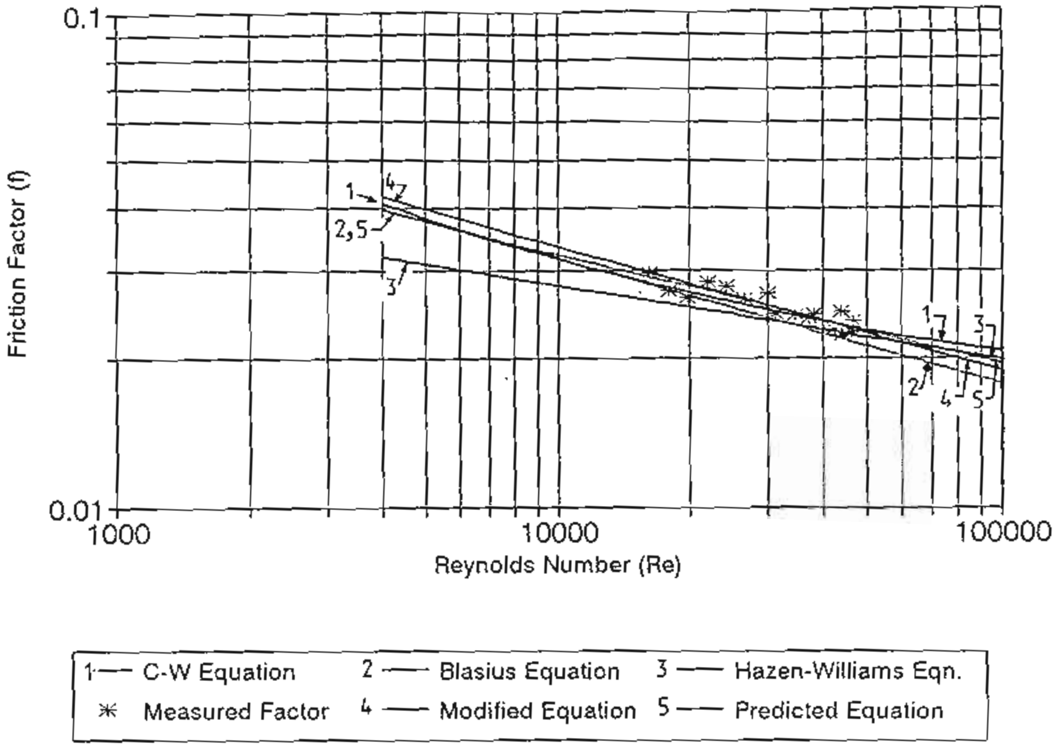


Fig (2a)Friction Factors and Predicted Curves for 21.5 mm Polyethylene Pipe



F(2b) Friction Factors and Predicted Curves for 21.5 mm Polyethylene Pipe

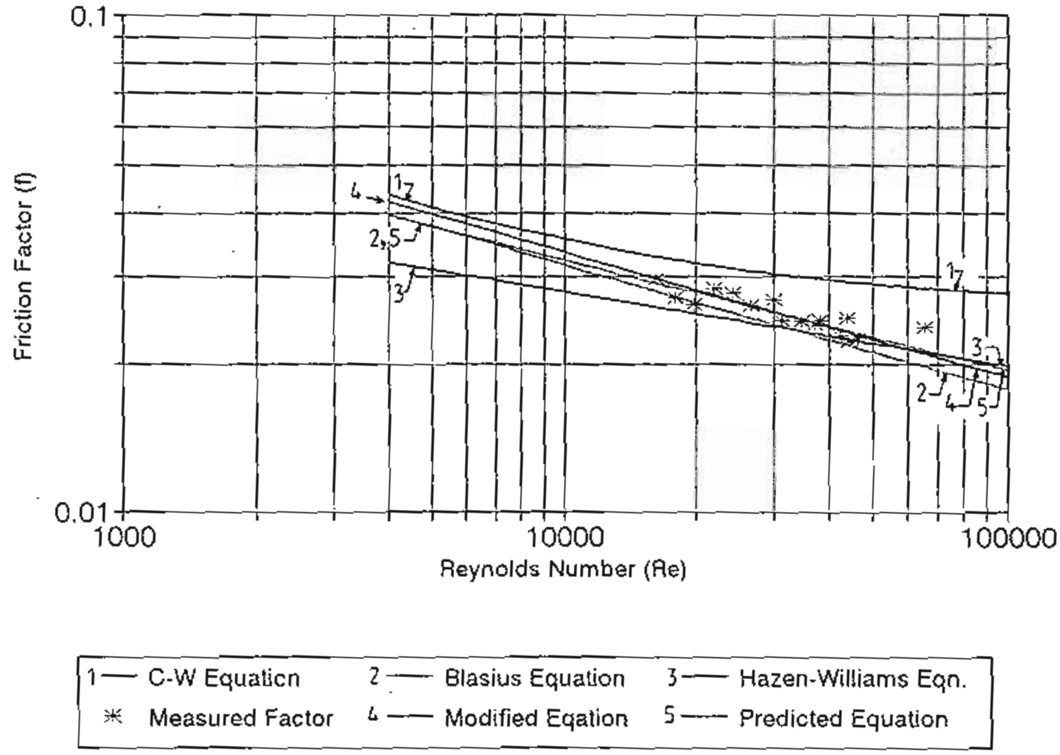
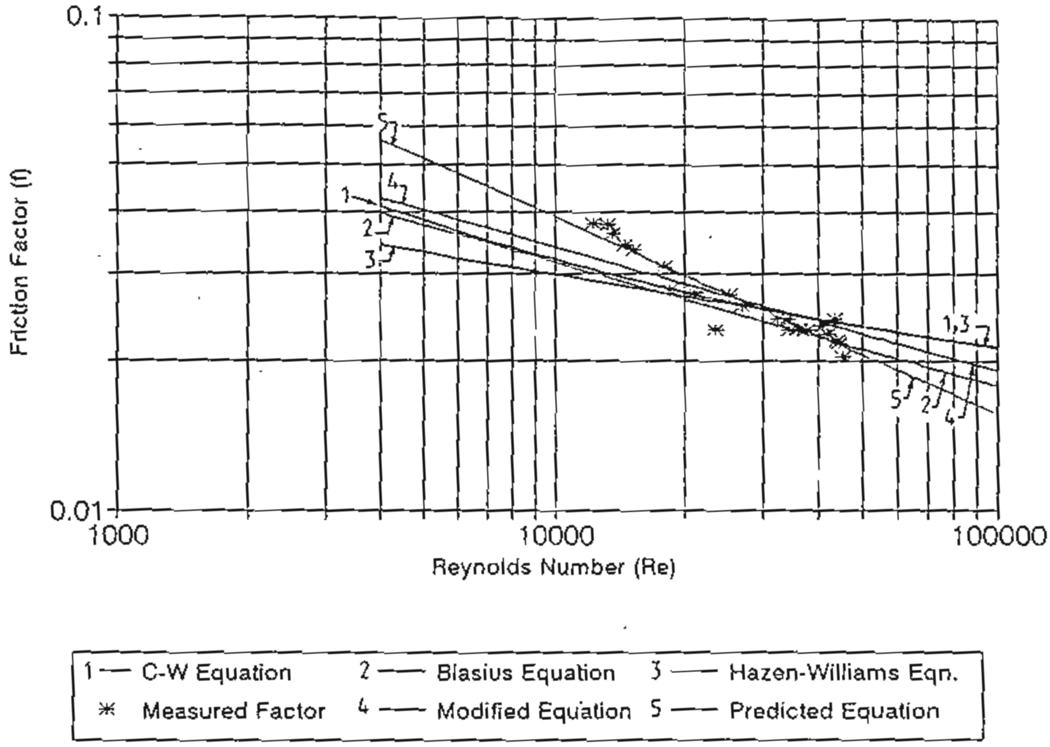


Fig (3a) Friction Factors and Predicted Curves for 18.5 mm Polyethene Pipe



Fig(3b) Friction Factors and Predicted Curves for 18.5 mm Polyethylene Pipe

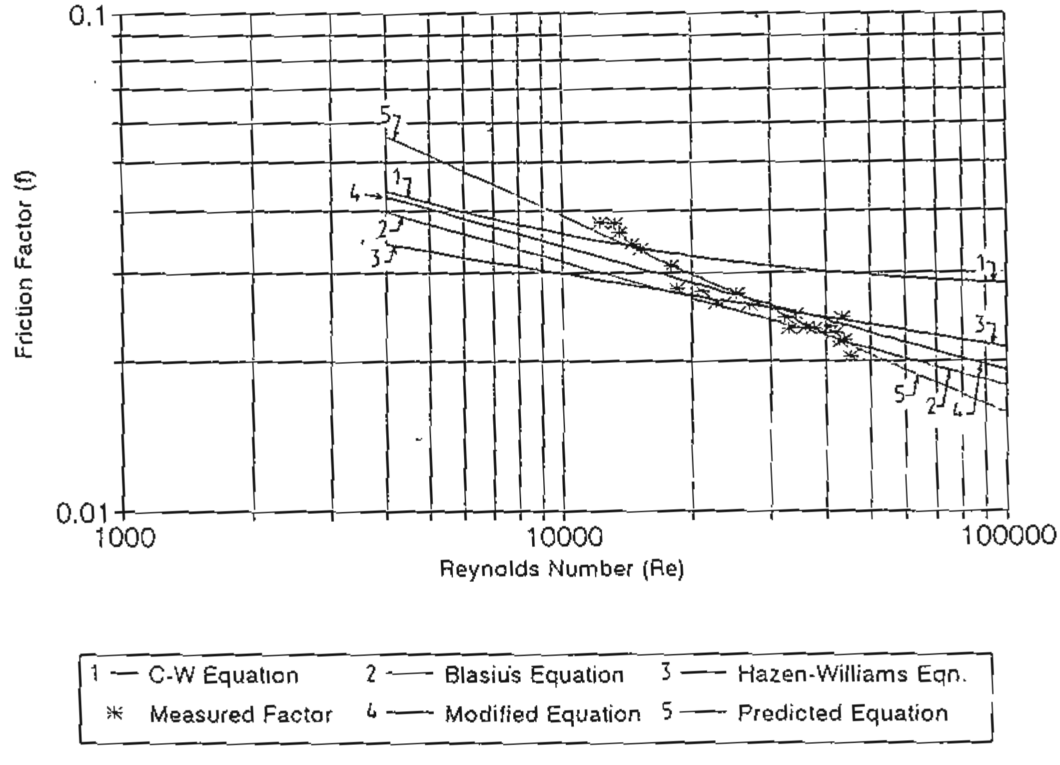


Fig (4a) Friction Factors and Predicted Curves for 17.0 mm Polyethylene Pipe

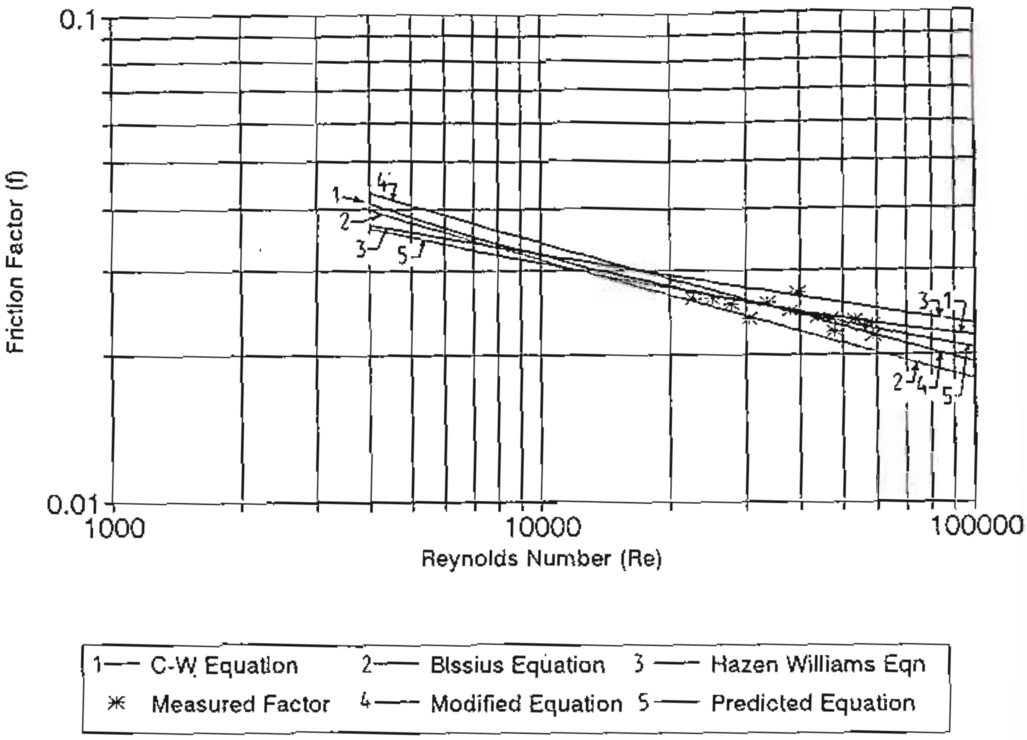
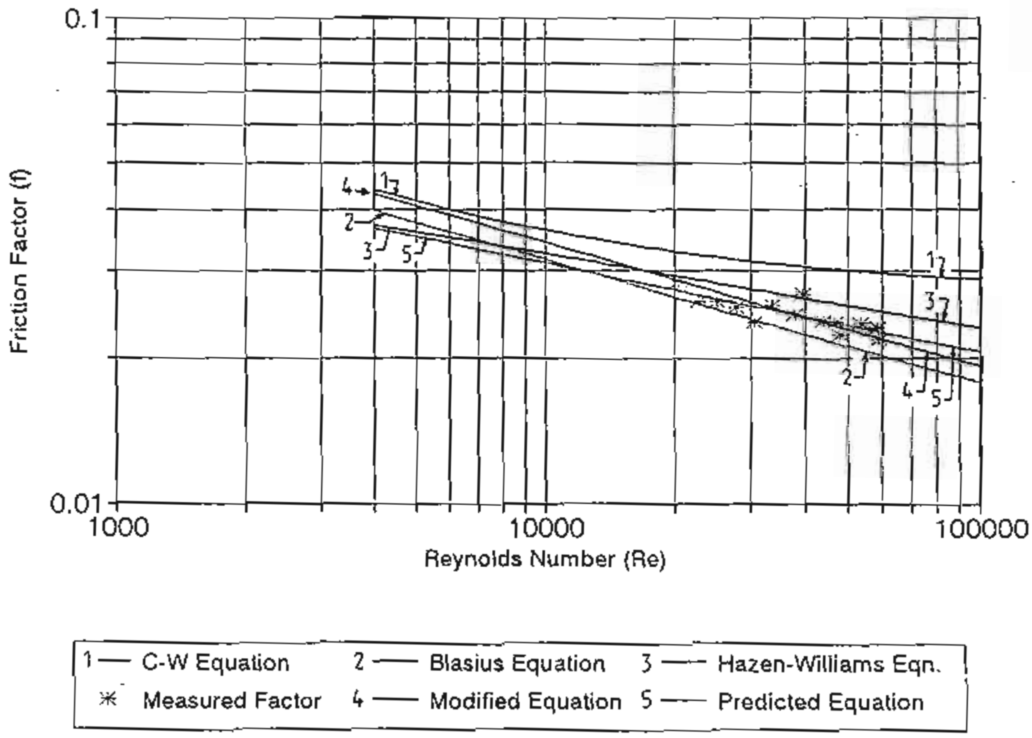
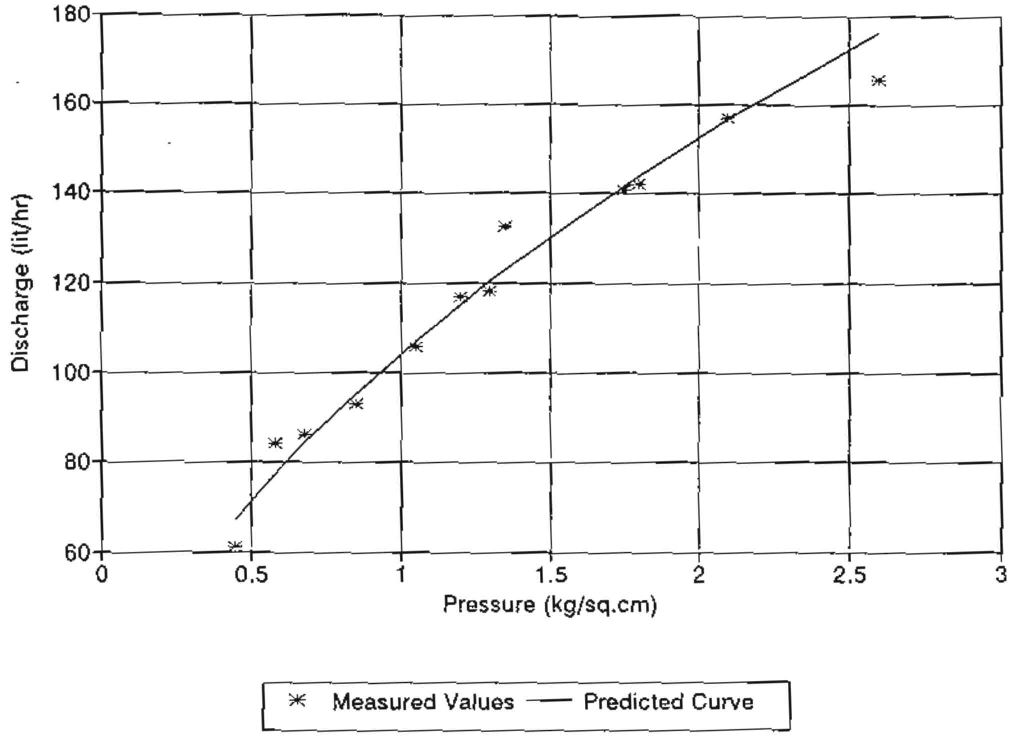


Fig (4b) Friction Factors and Predicted Curves for 17.0 mm Polyethylene Pipe



Fig(5a) Relationship between Discharge& Pressure for Orifice in 21.5 mm Pipe



Fig(5b) Relationship between Discharge& Pressure for Orifice in 18.5 mm Pipe

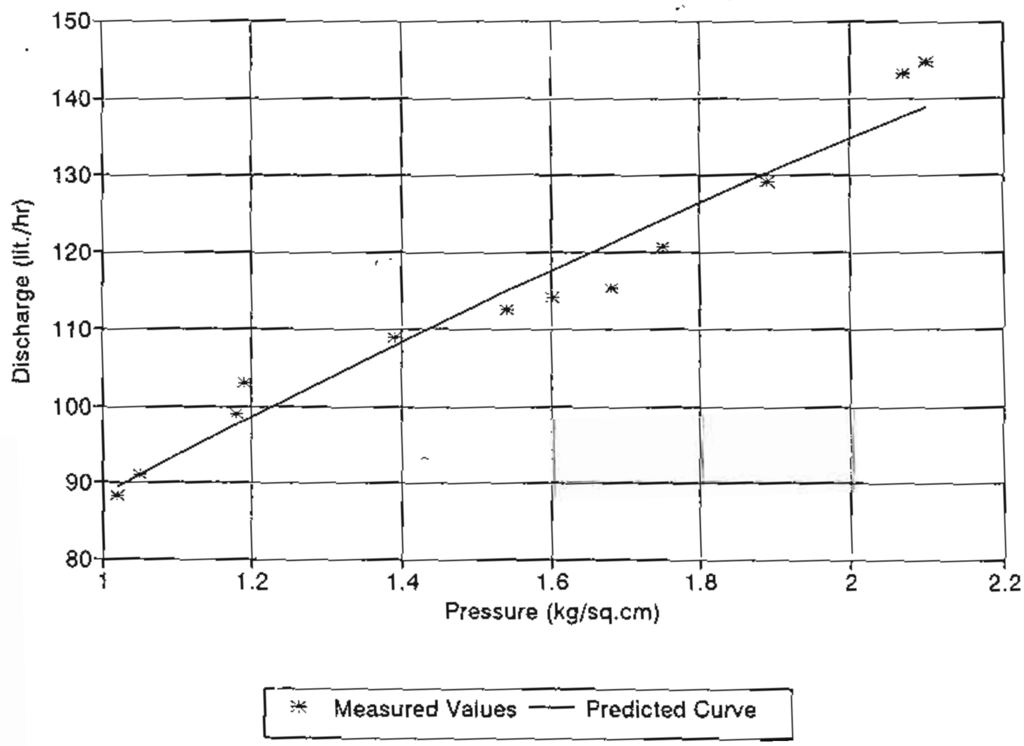


Table (1) Estimated Roughness Height (K) for Polyethylene Pipes Using Regression Analysis from Different Sources.

No.	Inside Diameter mm	$K \times 10^{3}$ mm	Source of Data
1	26.0	9.14	Von Bernuth,R. and Wilson,T.(1989)
2	21.0	64.0	Urbina (1979)
3	16.0	18.4	Von Bernuth,R. and Wilson,T.(1989)
4	15.7	9.91	Norum (1983)
5	15.5	2.48	Paraquierma (1977)
6	14.4	50.6	University of Tennessee.(1989)
7	14.0	57.6	Urbina (1979)
8	14.0	29.7	Von Bernuth,R. and Wilson,T.(1989)
9	8.9	0.58	Urbina (1979)

Table (2) Statistical Analysis, Using SAS Program, Power Relationship between Friction Factor (f) and Reynolds Number (R_e).

Pipe Diameter	Analysis of Variance				Parameter Estimate			Durbin watson coefficient
	F	prob>F	R^2	R^2 adj	T		prob>T	
21.5mm LN(Y)	57.6620	0.0001	0.8046	0.7907	Intercept	-1.406	0.0003	2.319
					LN(X)	-22.0	0.0001	
18.5mm LN(Y)	243.954	0.0001	0.9242	0.9202	Intercept	0.4348	0.1105	0.815
					LN(X)	-0.399	0.0001	
17.0mm LN(Y)	29.464	0.0001	0.6939	0.6704	Intercept	-1.832	0.0001	2.136
					LN(X)	-0.178	0.0001	
3 pipes LN(Y)	213.61	0.0001	0.8073	0.8035	Intercept	-0.593	0.0068	0.807
					LN(X)	-.2975	0.0001	

N.B. Y=f X=R_e.