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DETERMINATION OF A RELIABLE VALUE OF FRICTION FACTOR FOR PVC PIPES

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تعيين أنسب القيم لمعامل الاحتكاك في الانابيب (pvc) البلاستيك

خلاصة

يؤثر معامل الاحتكاك مباشرة في تحديد أقطار الانابيب المستخدمه في شبكة الانابيب وكذلك في قدرة المضخات المطلوبه وهذا بدوره يؤثر على التكاليف ،
ويوجد أكثر من معادله لتحديد الفواقد في الانابيب منها ماهو رياضي دقيق مثل معادله دارسي فيسباخ والباقي معادلات تجريبيه مثل هازن وليامز ومانينج وتشيزي وسكوبي وكلها تعتمد على قيمة معامل الاحتكاك ،
ويميل المهندسون الى استخدام المعادلات التجريبية الاخيره للسهولة في الاستخدام ولاستخدام قيمة واحده لمعامل الاحتكاك بغض النظر عن خصائص السريان وفي هذا البحث تم استنتاج العديد من الصور لمعادلات السرعه ومعامل الاحتكاك والفواقد ثم تم أجراء بحث معملي علي عدد من الانابيب البلاستيك باقطار مختلفة لعمل المقارنه بين الطرق المختلفه واستنتاج معامل الاحتكاك المناسب المستخدم في كل معادله ومقارنة النتائج بالكود المصري ،
وقد توصل البحث الي تحديد انسب القيم لمعاملات الاحتكاك التي يجب استخدامها في المعادلات المختلفه المستخدمه في حساب الفواقد في الانابيب (pvc) البلاستيك باقطار أقل من ١٠٠ مم

Abstract

Hydraulic friction loss in pipelines directly affects pipe and pump sizing as well as the hydraulic balance of networks. The turbulent behavior of flowing water is highly complex because it is not predictable fully by mathematical operations based on properties of water and fundamental physical laws. All friction head-loss equations have an uncertainty in the estimation of pipe interior surface roughness.

The study attempts to find the most reliable equation to determine the head loss from the most widely used pipe friction equations and examines the accuracy of friction factor in Hazen-Williams (H-W), Manning (Mn) . Chezy (Ch) ,Scobey (Sc) ,and Darcy-Weisbach (D-W) equations.

Introduction

The determination of friction head losses in pipelines is an important engineering factor in the design of pipe networks that affects total cost as well as the hydraulic balance of the network. Operating cost is affected by pipe sizes, pipe materials and flow properties. Many

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pipeline and irrigation engineers use empirical equations to determine friction head losses due to their mathematical simplicity rather than the more theoretical equation of Darcy- Weisbach. However one major limitation of the empirical equations is that a single roughness factor is usually assumed for all pipe sizes and flow velocities. Due to such an assumption of a constant friction factors, the calculated head losses by the empirical equations may differ significantly from those calculated by the Darcy- Weisbach equation.

Although no exact solutions are available from the general differential equations for turbulent flow, in fact that turbulent flow occurs more frequently in most commercial applications.

The objective of this study is to identify different friction coefficient values for the various empirical equations to be used with certain ranges of pipe diameters and flow conditions.

Velocity and Friction Losses

Most of the equations used for relating velocity to hydraulic slope, size, and roughness of the conduit belong to a family having general form

$$V=KS^{a}R^{b} \qquad (1)$$

or

$$V=K_{1}S^{c}Q^{d} \qquad (2)$$

in which V = mean flow velocity m/s ,K, K_1 = general symbols for the coefficients representing roughness of the pipe, S = hydraulic slope, R = hydraulic radius, Q = discharge and a, b, c, d = empirical constant exponents.

Though the Darcy- Weisbach equation is fundamentally more sound than other empirical and approximate equations, pipeline and irrigation engineers most commonly use the Hazen-Williams equation due to its computational simplicity. When using empirical equations such as the H- W, Mn, Ch, and Sc usually one friction coefficient for all pipe size and flow ranges is assumed, which simplifies head-loss calculations usually at expense of accuracy.

It is often required that an estimate can be made of the velocity V, or the quantity of flow then predictions can be made of V by the following equations in which R could be replaced either by the discharge Q or the wetted area A, and the corresponding friction loss (h_f) equations are also presented.

1- Darcy - Weisbach (D-W)

$$V=(8gf^{-1})^{0.5}S^{0.5}R^{0.5}=8.86f^{-0.5}S^{0.5}R^{0.5} \qquad (3)$$

or

$$V=2.08f^{-0.4}S^{0.4}Q^{0.4} \qquad (4)$$

or

$$V=3.39f^{-0.667}S^{0.667}A^{0.667} \qquad (5)$$

and

$$h_f=\frac{fLV^2}{2gD} \qquad (6)$$

2- Hazen - Williams (H-W)

$$V=0.85C_{HW}S^{0.54}R^{0.63} \qquad (7)$$

or

$$V=0.48C_{HW}^{0.76}S^{0.41}Q^{0.24} \qquad (8)$$

or

$$V=0.38C_{HW}S^{0.54}A^{-0.32} \qquad (9)$$

and

$$h_f=6.81C_{HW}^{-1.852}LD^{-1.167}V^{1.852} \qquad (10)$$

3-MANNING (Mn)

$$V=\frac{1}{n}S^{0.5}R^{0.667} \qquad (11)$$

or

$$V=0.531n^{1.33}S^{0.375}Q^{0.25} \qquad (12)$$

or

$$V=0.43n^{-1}S^{0.5}A^{0.33} \qquad (13)$$

and

$$h_f=6.35n^2LD^{-1.333}V^2 \qquad (14)$$

4-CHEZY (Ch)

$$V = C_{Ch}S^{0.5}R^{0.5} \tag{15}$$

or

$$V = 0.603C_{Ch}^{0.8}S^{0.4}Q^{0.2} \tag{16}$$

or

$$V = 0.53C_{Ch}S^{0.5}A^{0.25} \tag{17}$$

and

$$h_f = 4C_{Ch}^{-2}LD^{-1}V^2 \tag{18}$$

5-SCOBEY (Sc.)

$$V = C_{Sc}S^{0.53}R^{0.63} \tag{19}$$

or

$$V = 0.545C_{Sc}^{0.76}S^{0.4}Q^{0.24} \tag{20}$$

or

$$V = 0.45C_{Sc}S^{0.53}A^{0.32} \tag{21}$$

and

$$h_f = 5.196C_{Sc}^{-1.887}LD^{-1.1886}V^{1.887} \tag{22}$$

in which g= gravitational acceleration, f= friction coefficient, D= pipe diameter, C_{HW} =H.W.constant, n= Mn roughness, C_{Ch} = Ch. constant, C_{Sc} = Sc. constant, h_f = friction head loss, and L = pipe length.

The following equation gives the relationship between the friction coefficient of D-W and H-W equation

$$f_{HW} = 13.62gC_{HW}^{-1.852}D^{-0.167}V^{-0.148} \tag{23}$$

in which f_{HW} = the corresponding D-W friction factor, which if used in the D-W equation instead of that calculated by the Colebrook-White equation or others or by using Moody diagram for the given flow conditions will give equal frictional head loss due to that calculated by the H-W equation.

Similarly, the following relationships between the friction coefficient of D-W and Mn, Ch, and Sc are obtained

$$f_{Mn} = 12.699 g n^2 D^{-0.333} \tag{24}$$

$$f_{Ch} = 8 g C_{Ch}^{-2} \tag{25}$$

$$f_{Sc} = 10.392 g C_{Sc}^{-1.887} D^{-0.1886} V^{-0.113} \tag{26}$$

The corresponding friction coefficients are calculated according to eqns. 23 , 24 , 25 , and 26 and are presented in table (2). It is seen that friction coefficients calculated by the above methods have the same values as given by D-W equation. An accurate value of friction coefficient, using Colebrook - White (C-W) equation depends on the good estimation of the relative roughness (K_s/D) and Reynolds number R_n.

Experimental Investigation Setup

A series of PVC pipes of different sizes are considered and are fed from a high tank (15 m above pipe centerline) by a 100 mm diameter pipe which is provided with a Venturimeter to measure the discharge, flow meter to determine the volume of water during a certain time, and a valve to control the flow through the system. The Venturimeter is calibrated and its discharge coefficient is determined.

Two pressure gauges are connected to the pipes besides a manometer to measure the difference in head loss between two points 10 m apart as shown in Fig. (1).

The friction factors of Ch, Mn, H-W, and Sc equations are determined and are compared with the experimental measurements made on 47, 59.5, and 74.5 mm ID PVC pipes as shown in table (1)

Procedure

Since all friction equations require some input parameter to characterize pipe interior roughness, they all share the uncertainties involved in such a measurement. However, the D-W equation accounts for other variables that influence the hydraulic frictional losses in pipe flow. By using the control valve, various discharges for each pipe could be measured and analyzed as shown in table (1).

Determination of the variation of C_{HW} with respect to f may be found by rearranging Eq.(24) in terms of C_{HW} and replacing f_{HW} with f then

$$C_{HW} = 4.1 g^{0.54} D^{-0.09} V^{-0.08} f^{-0.54} \tag{27}$$

Similarly, Eqns. (24, 25, 26) are rearranged in terms of n instead of f_{Mn} , C_{Ch} instead of f_{Ch} and C_{Sc} instead of f_{Sc} then

$$n = 0.281 f^{0.5} D^{0.167} g^{-0.5} \tag{28}$$

$$C_{Ch} = 2.83 f^{-0.5} g^{0.5} \tag{29}$$

$$C_{Sc} = 3.458 g^{0.53} D^{-0.1} V^{-0.06} f^{-0.53} \tag{30}$$

In order to check the validity of the coefficient of friction values given by the Egyptian Code, a comparative analysis is made. Two pipe diameters with two different values of velocity are used. These are a pipe with ID 100 mm and V equals 3 m/s and another pipe with ID 71 mm and V equals 1.5 m/s. The energy losses per unit length of each pipe were calculated using the Egyptian Code coefficient of friction and the coefficient of friction determined by this study by applying the five equations considered in this study as shown in table (4). It seems clear from the results that the losses obtained using the Egyptian Code of friction coefficient for PVC pipes varies greatly with errors exceeds 100% in some cases. However, using the coefficient of friction based on the present study, the results show very small deviation less than 2%.

Another comparison is made to determine the energy losses per unit length based on the Moody diagram. The Egyptian Code for PVC pipes gives a value of 0.03 mm for roughness height (K_s). If this value is used with a pipe ID 100 mm, V equals 3 m/s and kinematic viscosity (ν) equals 0.0897×10^{-6} m^2/s then f from Moody diagram is 0.0168 and h_f/l equals 0.0771. However, if K_s equals 0.0015 as an average value as given by Hansen et al. (1979), Jeppson (1976) and King (1954), then the pipe could be considered as a smooth pipe, and Blasius equation can be applied to give the value of f:

$$f = \frac{0.3164}{R_n^{0.25}} = 0.0132 \qquad (31)$$

then h_f/l equals 0.061. This value agrees well with the value obtained from the present study (h_f/l = 0.0615). It can be concluded that the assumption of a smooth pipe (for PVC pipes) gives better results than the corresponding values given by using the roughness height according to the Egyptian Code.

Summary and Conclusions

Head loss in pipes is an important consideration for optimum design of pressurized systems. Several expressions for head loss can be given which already presented, Eqns. 6, 10 ,14, 18, and 22. Although these expressions are empirical except D-W equation.

To determine the important friction factors (f, C_{HW}, C_{Mn}, C_{Ch} and C_{Sc}), Several pipes are tested with length of 10 m. The region of entrance boundary layer is avoided and then the measurements are recorded. Many readings for every pipe are registered as shown in table (1). Then the coefficient factors are calculated by using Eqns 6, 10, 14, 18, and 22 as shown in table (3). From table (2), it seems that one value of coefficient can be used as an average value, where $f_{D\text{-}W}$ = 0.0134, C_{HW} = 165, n = 6.5×10^{-3} , C_{Ch} = 76.6, and C_{Sc} = 138 which are calculated from Eqns 6, 10, 14, 18, and 22 and compared with their values which are calculated by Eqns 27, 28, 29, and 30. It is noticed that the difference is negligible where it is less than 1%.

Table (2) represents the D-W coefficient of friction which is calculated by Eqns 6, 23, 24, 25, and 26, and it is seen that the reliable value of f equals 0.0134 can be used for PVC pipes less than 100 mm ID. The study also revealed that the coefficient of friction given by the Egyptian Code is no reliable. It gives deviation of 100% from the measured values in some cases. Furthermore, PVC pipes could be considered as smooth pipe if the Moody diagram is to be used for determination of head losses.

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Table (1) The Hydraulic Measurement Data

L=10 m T=25° C υ= 0.897E-6 m2/sec

	ID=47 mm					ID=59.5 mm					ID=71 mm				
No.	hl mm Hg	∀ m3	T sec	hl m of w	Q lit/sec	hl mm Hg	∀ m3	T sec	hl m of w	Q lit/sec	hl mm Hg	∀ m3	T sec	hl m of w	Q lit/sec
1	340.0	0.5	54.0	4.284	9 260	420.0	1	49.8	5.292	20.10	288	1	42.00	3.63	23.81
2	335.0	0.5	53.0	4.221	9.430	375.0	1	53.0	4.725	18.87	242	1	45.00	3.05	22.22
3	305.0	0.5	56.0	3.843	8.930	350.0	1	57.0	4.410	17.54	216	1	47.85	2.72	20.90
4	495.0	0.5	43.0	6.237	11.63	283.0	1	60.5	3.366	16.53	182	1	52.00	2.29	19.23
5	457.5	1.0	90.5	5.765	11.05	247.5	1	66.5	3.119	15.04	148	1	58.35	1.87	17.14
6	420.0	0.5	46.0	5.292	10.87	203.0	1	75.0	2.558	13.33	118	1	66.25	1.49	15.09
7	390.0	1.0	49.0	4.914	10.10	162.0	1	85.0	2.041	11.76	83	1	78.60	1.04	12.72
8	350.0	0.5	52.0	4.410	9.62	122.5	1	99.0	1.544	10.10					
9	307.5	1 0	111.5	3.876	8.97	80.0	1	123.5	1.008	8.10					
10	270.0	0.5	59.5	3.402	8.40	47.0	1	171.0	0.592	5.85					
11	197.0	0.5	71.5	2.482	6.99										
12	125.0	0.5	94.0	1.575	5.32										

Table (2) The Hydraulic Calculations and Coefficient of Friction from Eqns (6), (10), (14), (18), (22), and (31)

No.	ID=47 mm							
	V m/sec	f D.W.	f H.W.	f Mn	f Ch	f Sc	f smooth	Rn
1	3.07	0.0150	0.0154	0.0154	0.0154	0.0154	0.0160	160858
2	4.03	0.0140	0.0140	0.0140	0.0140	0.0140	0.0150	211159
3	4.84	0.0133	0.0133	0.0134	0.0134	0.0134	0.0143	253601
4	5.17	0.0133	0.0133	0.0134	0.0134	0.0133	0.0128	270892
5	5.54	0.0133	0.0132	0.0133	0.0133	0.0132	0.0138	290279
6	5.82	0.0133	0.0130	0.0134	0.0134	0.0134	0.0136	304950
7	6.27	0.0124	0.0124	0.0124	0.0124	0.0124	0.0134	328528
8	6.37	0.0130	0.0130	0.0130	0.0130	0.0130	0.0133	333768
9	6.70	0.0128	0.0128	0.0128	0.0128	0.0128	0.0131	351059
10	5.15	0.0134	0.0133	0.0134	0.0134	0.0133	0.0140	269845
11	5.44	0.0130	0.0130	0.0131	0.0132	0.0130	0.0138	285039
12	5.34	0.0139	0.0138	0.0139	0.0139	0.0138	0.0139	279799
Mean		0.0134	0.0134	0.0135	0.0145	0.0134	0.0139	

Table (2) (Cont)

ID=59.9 mm								
No.	V m/sec	f D.W.	f H.W	f Mn	f Ch	f Sc	f smooth	Rn
1	7.2	0.012	0.012	0.012	0.012	0.012	0.012	477128
2	6.8	0.012	0.012	0.012	0.012	0.012	0.012	450396
3	6.3	0.013	0.013	0.013	0.013	0.013	0.013	418556
4	5.9	0.012	0.012	0.012	0.012	0.012	0.013	394013
5	5.4	0.012	0.012	0.013	0.012	0.012	0.013	358857
6	4.8	0.013	0.013	0.013	0.013	0.013	0.013	318063
7	4.2	0.013	0.013	0.013	0.014	0.013	0.014	295929
8	3.6	0.014	0.014	0.014	0.014	0.014	0.014	240786
9	2.9	0.014	0.014	0.014	0.014	0.014	0.014	193027
10	2.1	0.016	0.016	0.016	0.016	0.016	0.014	139298
Mean		0.013	0.013	0.013	0.013	0.013	0.013	

Table (2) (Cont.)

ID=71 mm								
No.	V m/sec	f D.W.	f H.W.	f Mn	f Ch	f Sc	f smooth	Rn
1	6.01	0.0140	0.0145	0.0145	0.0145	0.0145	0.0120	526450
2	5.61	0.0135	0.0134	0.0135	0.0135	0.0134	0.0120	491238
3	5.28	0.0136	0.0135	0.0136	0.0136	0.0136	0.0130	462341
4	4.86	0.0135	0.0135	0.0135	0.0135	0.0135	0.0130	425564
5	4.33	0.0139	0.0139	0.0139	0.0139	0.0139	0.0130	379155
6	3.81	0.0139	0.0139	0.0139	0.0139	0.0139	0.0136	333622
7	3.21	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	281083
Mean		0.0138	0.0138	0.0138	0.0138	0.0138	0.0130	

Table (3) Values of D.W., H.W., Mn., Ch., and Sc. Coefficients

ID=47 mm										
Calculated from measuring Eq. (6), (10), (14), (18) and (22)							Calculated Eq. (23), (24), (25), and (26)			
	V m/s	f D.W.	C Ch	nE-3 Mn	C H.W.	C Sc.	C Ch	nE-3 Mn	C H.W.	C Sc.
1	3.07	0.0150	71.36	6.68	161.3	134.42	72.37	6.59	163.61	136.37
2	4.03	0.0140	74.63	6.39	165.9	138.66	74.91	6.37	166.17	139.16
3	4.84	0.0133	76.55	6.23	178.1	140.91	76.86	6.21	168.35	141.43
4	5.17	0.0133	76.62	6.22	167.4	140.48	76.86	6.21	167.46	140.87
5	5.54	0.0133	76.96	6.20	167.4	140.56	76.86	6.21	166.54	140.29
6	5.82	0.0133	76.59	6.22	165.7	139.44	76.86	6.21	165.88	139.88
7	6.27	0.0124	79.51	6.00	171.5	144.43	79.60	6.00	171.26	144.52
8	6.37	0.0130	77.40	6.16	166.4	140.22	77.74	6.14	166.73	140.81
9	6.70	0.0128	78.27	6.09	167.7	141.46	78.34	6.09	167.45	141.55
10	5.15	0.0134	76.64	6.22	167.5	140.55	76.56	6.23	166.84	140.35
11	5.44	0.0130	77.25	6.17	168.1	141.27	77.74	6.14	168.85	142.15
12	5.34	0.0133	75.27	6.34	163.7	137.58	75.17	6.35	163.10	137.35
Mean		0.01333	76.62	6.22	166.8	140.91	76.79	6.21	166.78	140.39

Table (3) (Cont.)

ID=59.9 mm										
	Calculated from measuring Eq. (7), (16), (13), (10) and (19)						Calculated Eq. (25), (26), (24), and (27)			
	V m/s	f D.W.	C Ch	nE-3 Mn	C H.W.	C Sc.	C Ch	nE-3 Mn	C H.W.	C Sc.
1	7.2	0.012	81.09	6.12	169.6	142.8	80.92	6.13	168.77	142.41
2	6.8	0.012	81.33	6.10	170.2	143.2	80.92	6.13	169.54	142.90
3	6.3	0.013	77.87	6.37	164.2	138.0	77.74	6.39	163.37	137.60
4	5.9	0.012	80.62	6.15	173.3	145.4	80.92	6.13	171.48	144.12
5	5.4	0.012	79.27	6.26	169.7	142.2	80.92	6.13	172.70	144.89
6	4.8	0.013	77.78	6.33	167.4	140.0	77.74	6.39	166.96	139.86
7	4.2	0.013	76.24	6.50	166.8	139.2	77.74	6.39	168.75	140.98
8	3.6	0.014	75.22	6.59	166.5	138.5	74.91	6.63	164.14	136.81
9	2.9	0.014	74.82	6.63	168.0	139.1	74.91	6.63	167.01	138.60
10	2.1	0.016	71.89	6.99	161.6	133.1	70.07	7.08	159.45	131.66
Mean		0.013	77.61	6.40	167.7	140.2	77.68	6.40	167.22	139.98

Table (3) (Cont.)

ID=71.0 mm										
	Calculated from measuring Eq. (7), (16), (13), (10) and (19)						Calculated Eq. (25), (26), (24), and (27)			
	V m/s	f D.W.	C Ch	nE-3 Mn	C H.W.	C Sc.	C Ch	nE-3 Mn	C H.W.	C Sc.
1	5.46	0.0140	74.82	6.02	152.88	128.00	74.91	6.88	155.56	130.49
2	5.10	0.0135	76.33	6.70	160.07	133.74	76.29	6.76	159.52	133.55
3	4.79	0.0136	76.05	6.72	160.23	133.71	76.01	6.78	159.68	139.42
4	4.41	0.0135	76.16	6.70	161.55	134.59	76.29	6.76	161.38	134.74
5	3.93	0.0139	75.11	6.85	160.61	133.53	75.18	6.86	162.87	135.59
6	3.46	0.0139	75.09	6.86	162.21	134.52	75.18	6.86	164.54	134.62
7	2.92	0.0140	74.67	6.89	163.44	135.09	74.91	6.88	163.55	135.48
Mean		0.0138	75.46	6.67	160.14	133.31	75.54	6.83	161.01	134.84

Table (4) Comparison Between Various Methods

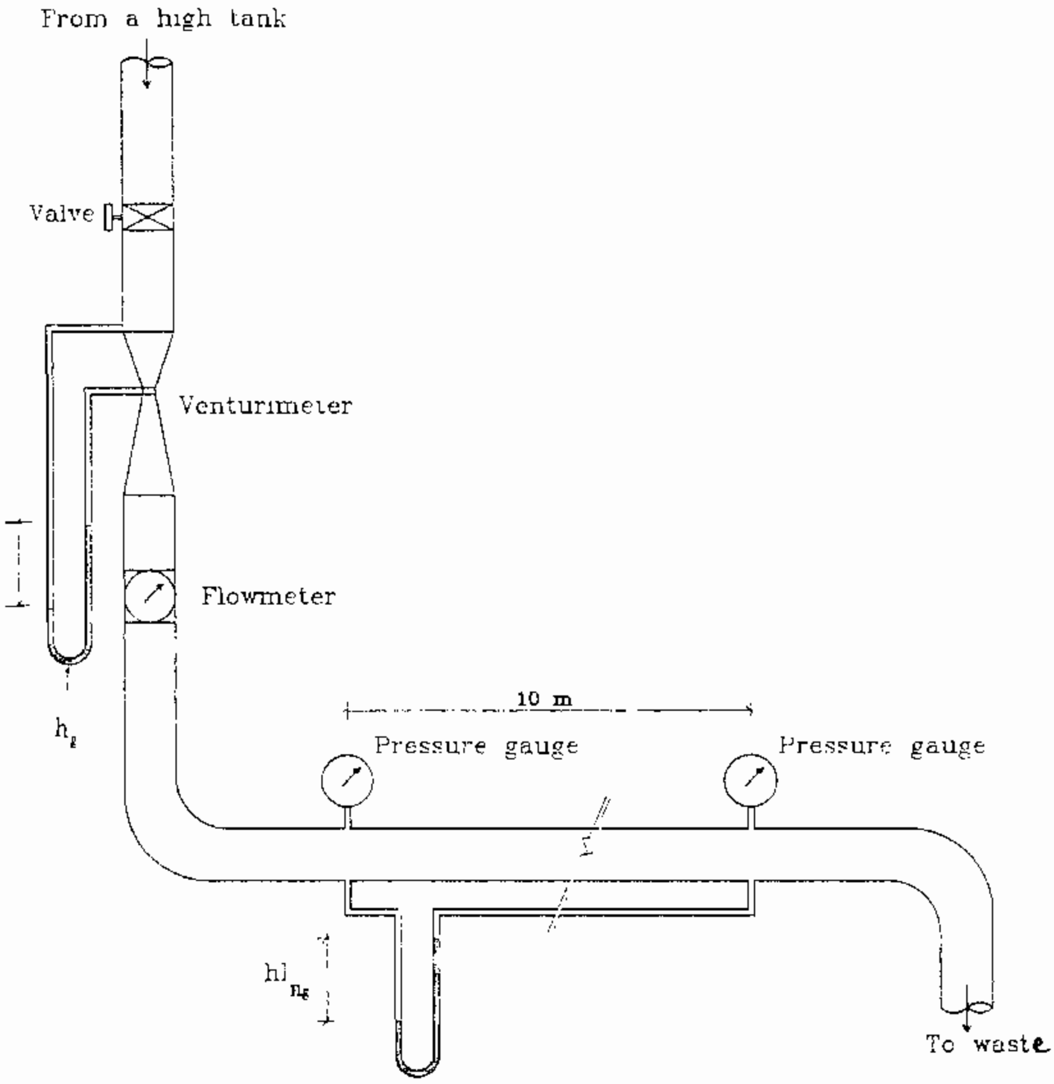
υ=0.897E-6 m2/sec at T=25 C

Method Name	ID=100 mm ,V=3m/s ,R=334448						ID= 71 mm, V=1.5 m/s, R=118729					
	Egypt Code			This Study			Egypt Code			This Study		
	f	h /l	%	f	h /l	%	f	h /l	%	f	h /l	%
D.W	0.01	0.0459		0.0134	0.0615		0.01	0.0162			0.0216	
H.W	150-155	0.0692	151	165	0.0598	97	150-155	0.0286	177		0.0247	114
Mn	0.011-0.015	0.2081	453	0.0068	0.0569	93	0.011-0.015	0.082	506		0.0225	104
Ch				76.6	0.0614	99.8					0.0216	100
Sc				138	0.0584	95					0.0237	110
Smooth				0.013	0.0597	97				0.017	0.0275	127
Moody	0.017	0.078	170				0.02	0.0324	200			

f = coeff. of friction

% = percentage of error compared with D W losses

h/l = loss per unit length (m)



Fig(1)
Experimental setup (schematic)