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A comparative study on head loss characteristics of same pipe material with different diameters in buried pipe distribution system

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ABSTRACT

A research work was conducted on buried pipe distribution systems in two different DTW irrigation schemes located in the villages of Dhitpur and Chongachain the sadar upazilla of Sirajganj district. The main objectives of the study were to determine and compare the head loss characteristics of flow through buried pipes made of cement concrete pipe and having different diameters. Air vents of the buried pipe were used as piezometers for the calculation of hydraulic grade line along the pipe length. The flow rate was measured by a cutthroat flume, placed in the open channel several meters away from the outlet of the buried pipe. This work shows that hydraulic properties of buried pipe such as frictional, entrance and exit losses, as well as friction factor are nonlinearly related to velocity of flow. Frictional, entrance and exit losses, as well as friction factor are significantly smaller in a large diameter pipe compared a small diameter pipe of same material for the same velocity of flow. This study reveals that, for a given velocity, the energy losses are significantly smaller in a large diameter pipe compared a small diameter pipe of same material. Exit loss is greater than the entrance loss except very low flow rates. This study suggests that, as the loss of head in a large diameter pipe compared a small diameter pipe of CC pipes, the former is particularly suitable for long buried pipe lines.

Introduction

Irrigation for agriculture plays a vital role in increasing crop production in Bangladesh. The performance of an irrigation system depends on engineering, agronomic, organizational and management practices. In fact, irrigation technologies have always been considered as one of the major primary contributors to agricultural development in this country. Obviously, various types of studies are carried out for addressing the issues and problems associated with both the operation and management of irrigation systems. Amongst these, Improvement of performance of water distribution system is the prominent one. For the development of command area of any irrigation project, proper water distribution system and its efficient management play a very important and vital role.

Water distribution in the minor irrigation sector is commonly used of open channel that's made of earthen in Bangladesh and have very low conveyance and distribution efficiencies, resulting in less irrigated area and high maintenance cost. It is fact that, traditional earthen channel distribution systems confront some physical obstructions and canals suffer from high seepage, leakage and evaporation losses. The buried pipe distribution system (BPDS) may be the best solution to these problems.

In a buried pipe distribution system, the pipelines are placed underground and cultivation can be done above the pipelines without interference to farming operations. If the pipelines are properly installed, they are very durable and the maintenance cost is low. Their placement below ground surface prevents any damage and eliminates water loss by evaporation. The systems are operated under pressure. Therefore, they can be laid uphill and downhill, thus permitting the delivery of water to areas not accessible when open channels are used. They do not become clogged by vegetation and windblown materials. With an underground pipeline system, the DTW need not be located at the highest point of the farm but may be at a location that provides the best water supply. No land needs to be reserved for right-of-way in the buried pipe distribution system (BPDS). This is not only an

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economic advantage but also a practical benefit when a large number of field plots belonging to different individuals are not required to be crossed to distribute water from a pumping well.

Despite the clear advantages and benefits of the buried pipe, some problems have been observed in the systems, for instance, unsatisfactory jointing methods and techniques, frequent leaks, faulty outlet valves, poor hydraulic design (using trial and error method) spillage from air vents, higher initial cost and so on.

Since BPDS uses low-pressure pipes, maximum pressure in the buried pipes should not exceed a limiting value. Therefore, the rate of head loss is an important parameter to be considered in the design of a BPDS. For a given pipe, the head loss per unit length of pipe again depends on discharge through the pipe.

The main objective of this work was to determine major and minor losses in buried pipe distribution systems having different pipe diameters and same pipe materials. The specific objectives were i) to study the friction loss parameters of selected schemes for different flow rates, ii) to determine the head losses at the entrance and exit of a buried pipe system for different discharges, and iii) to compare the head loss characteristics of buried pipe distribution system (BPDS) of different pipe diameters and same pipe materials.

Materials and Methods

The study schemes

To study the head loss characteristics of buried pipe with different diameters and same pipe materials of two DTW irrigation schemes were selected. The study sites were located in the villages of Dhitpur and Chongachain the sadar upazilla of Sirajganj district. The sites were about 10 km west of the upazilla headquarter. The diameters of the buried pipes in the study schemes were 20cm and 25cmand made of CC respectively.

A schematic diagram showing the hydraulics of flow in a buried pipe system is presented in Figure 1.In this work, the buried pipe distribution systems were run to measure the head losses in the pipe, as well as at the inlet and outlet, for different discharges. The flow rate was measured by a cutthroat flume placed in the open channel several meters away from the outlet of the buried pipe.

Head loss in pipe

Loss of head in feet of fluid, meaning loss of energy expressed in foot-pounds per pound of fluid, occurs in any flow of fluid through a pipe. The loss is caused by: (1) “pipe friction” along the straight sections of pipe of uniform diameter and uniform roughness and (2) changes in velocity or direction of flow. Losses of these two types are ordinarily referred to respectively as major losses and minor losses.

Loss of head due to pipe friction

Frictional losses in a pipe are considered to be a major loss. From Darcy-Weisbach formula, loss of head h_f is given by

$$h_f = f\frac{L}{D}\frac{V2}{2g}$$

Where,
f = coefficient of friction for pipe,dimensionless
L =length of pipe, m
g = acceleration due to gravity, m/s^2
V = velocity, m/s
D = diameter of pipe, m
h_f= head loss, m

This formula is of convenient form since it expresses the loss of head in terms of the velocity head in the pipe. Moreover, it is dimensionally correct since f is a numerical factor L/D is a ratio of lengths, and h_f and $V^2/2g$ are both expressed in units of length.

Value of f depends on pipe materials and velocity of flow. Value of f for different pipe materials and velocities are available in relevant textbooks.

Methodology

Before starting the experimental work, the buried pipelines, air vents, outlets, storage tank and open channels were properly checked to ensure that they are well in order. The best pipe line of the distribution systems of each study scheme was selected. Flow rate through the buried pipe under study was controlled by adjusting the cap plates of the inlets in the storage tank and the alfalfa valves. After starting the pump, sufficient time was allowed to elapse to stabilize the flow through the buried pipe. A cutthroat flume was placed in the open channel several meters away from the outlet for the measurement of discharge. The flume was installed with its floor horizontal, length wise and breadth wise.

Air vents of the buried pipe were used for the measurement of pressure head in the pipeline. When the flow through the pipe became steady, piezometric heads, h_1 and h_2 were measured with reference to an arbitrary datum as shown in Figure 1. Total head in the storage tank, H_i causing flow through the pipe and the total head H_0 at the outlet were also measured.

Loss of head in the pipe between the two air vents was calculated by subtracting h_2 from h_1. From this, loss of head in meter per 100 m length of pipe was calculated. The hydraulic grade line passing through h_1 and h_2 was extended backward and forward. From this line, potential head h_i in the pipe, just outside the storage tank, was estimated in order to calculate the entrance loss. Similarly potential head h_0 in the pipe just before the outlet was estimated from this hydraulic grade line for the calculation of exit loss.

Entrance loss h_{fi} in meter at the inlet was calculated from,

$h_{fi} = H_i - h_i - V^2/2g$

Exit loss at the outlet $h_{fo} = h_o - H_o + V^2/2g$

where, V is the velocity in meter per second through the buried pipe, H_i, h_i, H_o and h_o are in meter.

For the estimation of discharge, the upstream flow depth h_a and the downstream flow depth h_b were measured from the scales attached to the flume. The flow condition was determined from submergence ratio h_b/h_a and the flow rate was obtained.

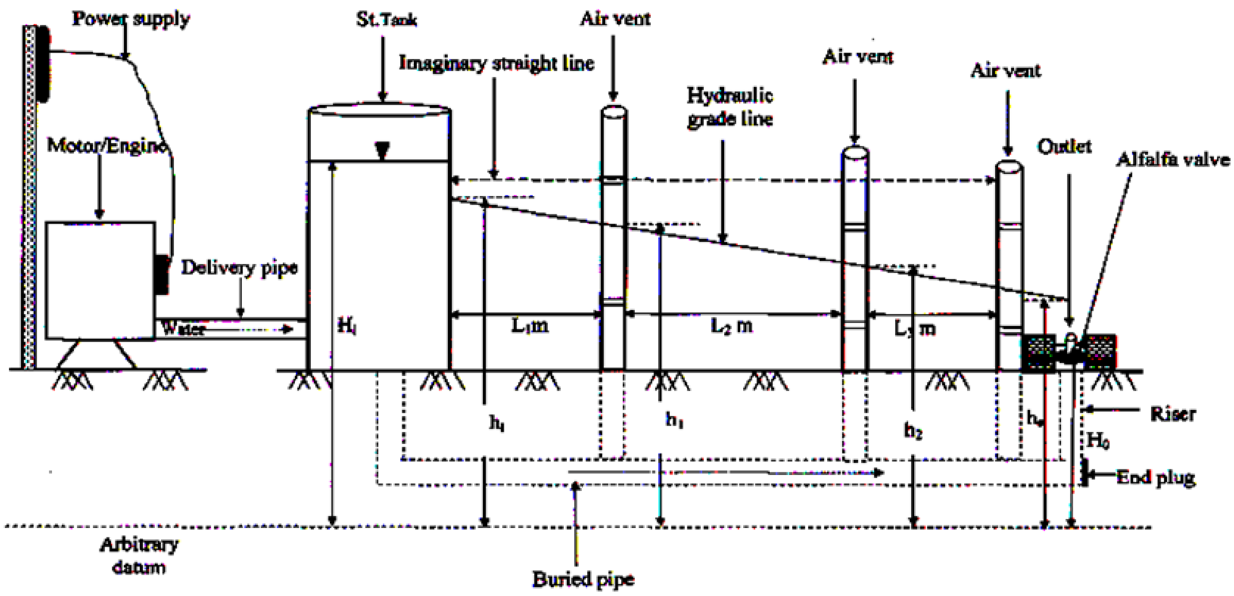

Figure 1: A schematic diagram of the hydraulics of flow in a buried pipe

After taking these measurements, for a particular discharge, flow to the selected pipe line was changed by adjusting the alfalfa valves of other pipe lines. Some time was allowed to elapse in order to stabilize the flow in the buried pipe. When the flow in the pipe became steady, H_i, h_1 h_2 H_o were measured for calculation of head losses and h_a and h_b for discharge. The work was repeated for several variations of discharge.

Results and Discussion

For each site, hydraulic properties of the buried pipe are calculated from measured data and summarized in Tables 1. Results obtained in different sites are sequentially presented below in tables and graphs.

Comparisons of hydraulic properties

The study shows that for the same velocity and same discharge, the frictional losses were different for different pipe diameter. As indicated in FigureA-1 and Figure B-1, the frictional loss is greater in 20cm pipe than that in 25cm pipe against the same velocity of 0.8 m/s.

Table A-1: Measurement of discharge data by cutthroat flume and pressure head at different points of 20 cm CC buried pipe.

Test No.	h_a (cm)	h_b (cm)	S= h_b/ h_a	Flow condition	Q(m^3/s)	$V^2/2g$	H_i(m)	h_i(m)	h_1(m)	h_2(m)	h_0(m)	H_0(m)
1	19.20	5.70	0.30	Free flow	0.0435	0.098	1.938	1.577	1.423	1.070	0.8700	0.4580
2	18.097	5.31	0.29		0.039	0.078	1.690	1.410	1.270	0.9560	0.7760	0.4260
3	16.750	4.83	0.29		0.032	0.053	1.35	1.135	1.035	0.808	0.676	0.394
4	15.24	4.39	0.28		0.028	0.040	1.120	0.9495	0.8708	0.6940	0.5933	0.366
5	13.97	4.05	0.29		0.025	0.033	0.929	0.7910	0.7260	0.5768	0.4910	0.3340
6	12.065	3.38	0.27		0.0204	0.022	0.6595	0.5555	0.5130	0.4160	0.3600	0.2610
7	11.589	3.10	0.27		0.017	0.015	0.5455	0.4565	0.4240	0.3490	0.3061	0.2350
8	10.319	2.80	0.27		0.0139	0.0097	0.4922	0.3955	0.3730	0.3213	0.2916	0.2275
9	9.684	2.62	0.27		0.0122	0.0077	0.4542	0.3545	0.3357	0.2926	0.2678	0.2085

Table A-2: Hydraulic properties for different discharges of 20 cm CC buried pipe

Discharge, Q (m^3/s)	Velocity, V (m/s)	Frictional loss,h_f(m/100m)	Friction factor, f	Entrance loss, h_{fi}(m)	Exit loss, h_{fo}(m)
0.0435	1.39	1.23	0.0249	0.263	0.510
0.039	1.24	1.09	0.027	0.202	0.448
0.032	1.02	0.79	0.029	0.165	0.335
0.028	0.890	0.61	0.030	0.131	0.267
0.025	0.80	0.52	0.031	0.105	0.190
0.0204	0.65	0.34	0.032	0.082	0.121
0.017	0.54	0.26	0.035	0.074	0.086
0.0139	0.44	0.18	0.037	0.084	0.074
0.0122	0.39	0.15	0.039	0.092	0.067

Table B-1: Measurement of discharge data by cutthroat flume and pressure head at different points of 25 cm CC buried pipe.

Test No.	h_a (cm)	h_b (cm)	S= h_b/ h_a	Flow condition	Q(m^3/s)	$V^2/2g$	H_i(m)	h_i(m)	h_1(m)	h_2(m)	h_0(m)	H_0(m)
1	20.80	6.17	0.30	Free flow	0.0496	0.050	1.337	1.130	1.040	0.843	0.761	0.425
2	19.53	5.79	0.30		0.0445	0.042	1.205	1.030	0.956	0.783	0.710	0.405
3	18.89	5.54	0.29		0.042	0.038	1.130	0.970	0.896	0.734	0.667	0.396
4	17.30	5.11	0.29		0.037	0.029	0.925	0.786	0.728	0.602	0.548	0.346
5	17.10	5.05	0.29		0.035	0.026	0.865	0.747	0.693	0.574	0.524	0.337
6	15.87	4.57	0.29		0.03	0.020	0.763	0.678	0.634	0.537	0.497	0.325
7	15.28	4.4	0.29		0.027	0.05	0.640	0.575	0.537	0.453	0.418	0.272
8	13.34	3.87	0.29		0.023	0.011	0.516	0.505	0.473	0.403	0.373	0.255
9	12.07	3.32	0.27		0.09	0.008	0.474	0.393	0.365	0.304	0.278	0.215

Table B-2: Hydraulic properties for different discharges of 25cm CC buried pipe

Discharge Q (m^3/s)	Velocity V (m/s)	Frictional loss h_f(m/100m)	Friction factor, f	Entrance loss h_{fi}(m)	Exit loss h_{fo}(m)
0.0496	0.98	0.61	0.031	0.157	0.386
0.0445	0.91	0.54	0.032	0.133	0.347
0.042	0.86	0.51	0.034	0.122	0.309
0.037	0.75	0.40	0.034	0.110	0.232
0.035	0.71	0.37	0.036	0.092	0.213
0.031	0.63	0.30	0.037	0.065	0.192
0.027	0.55	0.26	0.042	0.050	0.161
0.023	0.47	0.22	0.049	0.058	0.129
0.019	0.39	0.19	0.061	0.073	0.071

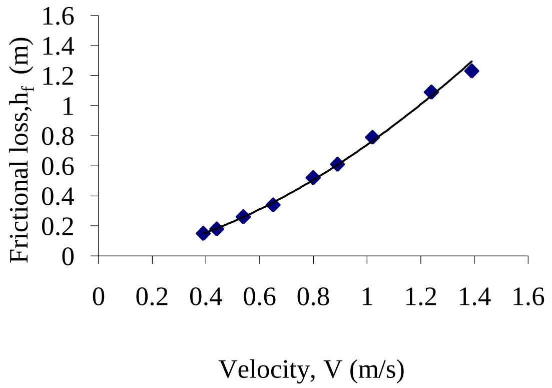

Figure A.1: Relationship between velocity and frictional loss for 20 cm CC buried pipe

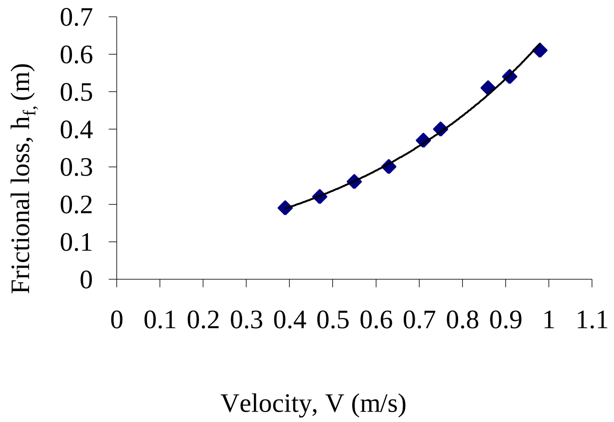

Figure B.1: Relationship between velocity and frictional loss for 25 cm CC buried pipe

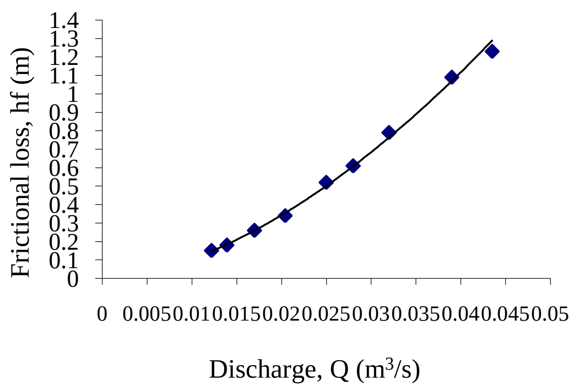

Figure A.2: Relationship between discharge and frictional loss for 20 cm CC

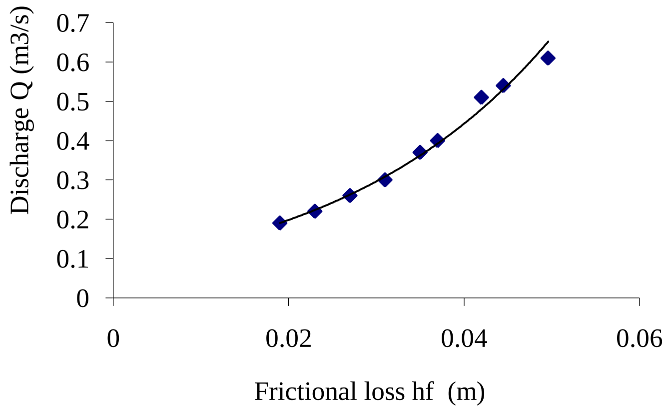

Figure B.2: Relationship between discharge and frictional loss for 25 cm CC buried pipe

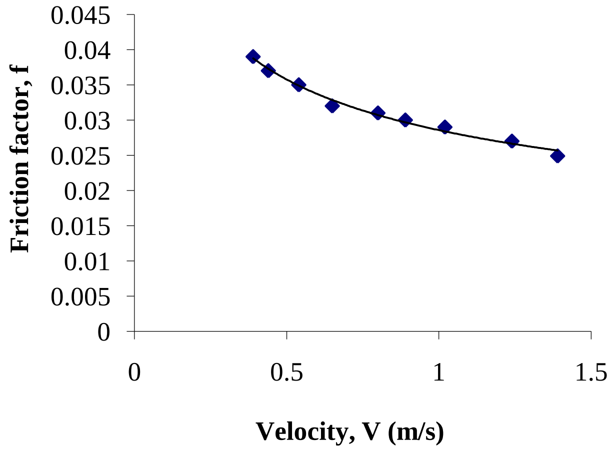

Figure A.3: Relationship between velocity and friction factor for 20 cm CC buried pipe

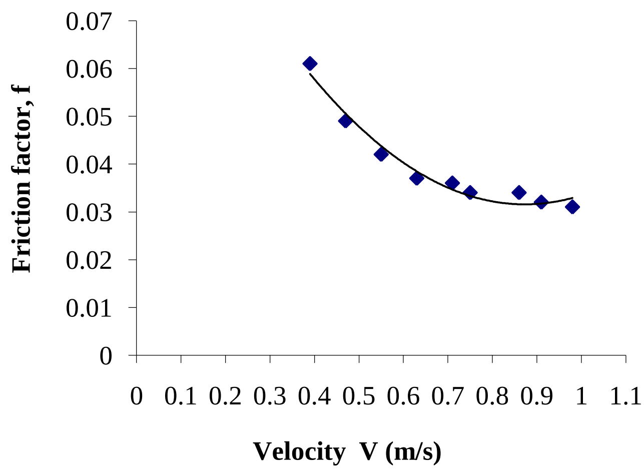

Figure B.3: Relationship between velocity and friction factor for 25 cm CC buried pipe

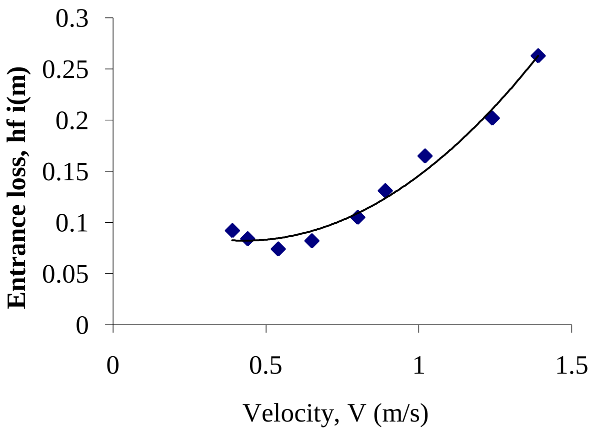

Figure A.4: Relationship between velocity and Entrance loss for 20 cm CC buried pipe

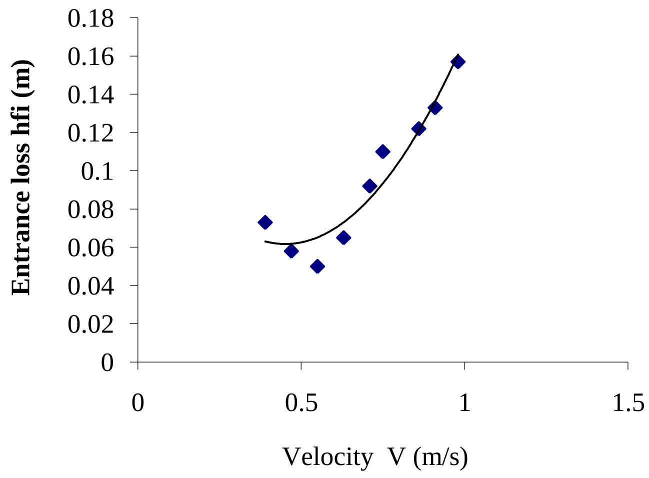

Figure B.4: Relationship between velocity and Entrance loss for 25 cm CC buried pipe

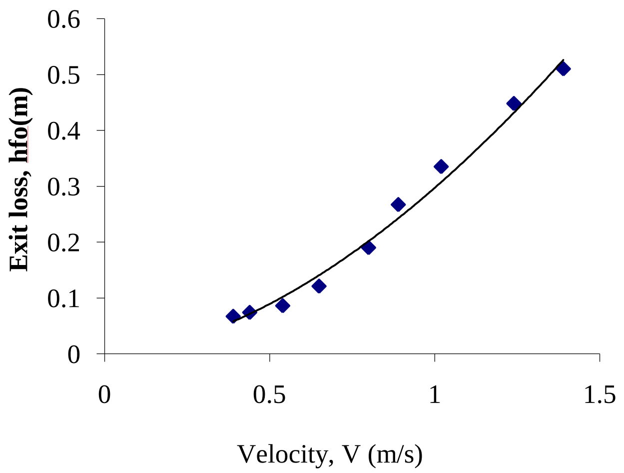

Figure A.5: Relationship between velocity and Exit loss for 20 cm CC buried pipe

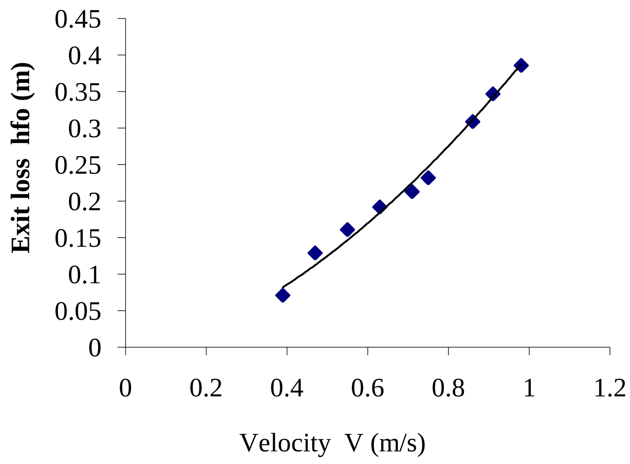

Figure B.5: Relationship between velocity and Exit loss for 25 cm CC buried pipe

Similarly, for the same discharge of $0.03 m^3/s$ (Figure A.2 and Figure B.2) frictional loss is again greater in the 20 cm CC pipe than that in 25cm CC pipe.

For the same velocity of flow, friction factor varies for different pipe diameters (Figure A.3 and Figure B.3). The friction factor is greater in 25cm pipe than that in 20 cm pipe against the same velocity of 0.8 m/s.

For the same velocity of flow, entrance and exit losses vary for different pipe diameters (Figure A.4, Figure B.4, Figure A.5 and Figure B.5). Entrance loss is greater in 20cm pipe than that in 25cm pipe against the same velocity of 0.8 m/s. The exit loss for a velocity of 0.8 m/s is greater in 25 cm pipe than that in 20 cm pipe.

From these results and discussion, it can be said that, the frictional loss nonlinearly related to both velocity and discharge. For the buried pipes of same material, frictional loss decreases with the increase of pipe diameter for the same velocity of flow.

The friction factor decreases nonlinearly with the increase of velocity of flow in a given buried pipe. For the pipes of same material, friction factor increases with the increase of pipe diameter.

The entrance loss initially decreases up to a certain increase of velocity and then it increases with the increase of velocity. For the pipes of same material, entrance loss increases with the decrease of pipe diameter for the same velocity.

Exit loss varies nonlinearly with the velocity of flow. For the buried pipes of same material, it increases; it increases with the decrease of the pipe diameter.

Conclusions

Hydraulic properties of buried pipe, such as frictional, entrance and exit losses as well as friction factor are nonlinearly related to velocity of flow. Frictional, entrance and exit losses are significantly smaller in a large diameter pipe compared to a small diameter pipe of same mater for a given velocity of flow. Exit loss is greater than the entrance loss except very low flow rates. As the loss of head is significantly smaller in a large diameter compared to a small diameter in CC pipe, the former is particularly suitable for long buried pipe lines.

Recommendations

Similar study should be carried out in other buried pipe irrigation schemes where pipes of other diameters are used. Large diameter in CC pipe is found to be superior in terms of pipe material of hydraulic properties. However, economic analyses need to be carried out to determine which of these is profitable to use in buried pipe distribution system.

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