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VARIATION OF FLOW ALONG A MULTIPLE OUTLETS PIPE WITH VARIOUS SPACING AND INFLOW WATER HEAD BASED ON PHYSICAL MODEL

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Abstract

Multiple outlets pipe can be used to distribute and collect fluids and have applications in various engineering fields, especially in the water supply system. For water transported along the manifold, there are variations in discharge from the pipe outlets due to friction head losses. A test rig is designed and fabricated for testing the variation of discharge from multiple outlets dead-end PVC pipe. The rig consists of a water supply tank, various diameters multiple outlet PVC pipes with a constant spacing of 1.5 m, and piezometers. The variation of discharge along the multiple outlets PVC dead-end pipe is studied under different hydraulic conditions. In this study, results showed that the variation in discharge along the pipe is mainly due to change in the piezometric head along with the pipe outlets. The change in the head along the dead-end multi-outlet pipe is mainly due to the accumulated friction losses. Besides, it is found that the spacing between outlets and the ratio of the diameter, DR (ratio between outlet diameter, d_o to the main pipe diameter, d) are factors that affect head loss along the multiple outlet PVC pipe. The change in Reynolds number along the multiple outlets PVC can be attributed to the decreasing flow. Thus, the coefficient of friction is varied accordingly. A better uniformity, (last outlet discharge, q_n/first outlet discharge, q_1) is obtained with bigger S/d ratio (ratio of the spacing between outlets, S to manifold diameter, d). For simplicity, many literatures assumed that the coefficient of friction along multiple outlet pipes is constant. In fact, the results of this study showed that this assumption is not accurate.

Keywords: Diameter, Head loss, Multi outlets, Physical modelling, PVC pipe, Spacing, Uniformity.

1. Introduction

A closed conduit with branches or multiple outlets distributed along the length is called manifold [1]. Manifolds can be used to distribute and collect fluids. In applications, the manifolds are used in various engineering fields such as civil engineering, irrigation engineering, chemical engineering and mechanical engineering. Applications of the manifold in civil engineering found in water supply systems, sewage disposal, water and wastewater treatment plant processes, navigation locks and hydroelectric power penstocks [1].

The most common application of manifolds is on water supply system and irrigation systems (e.g., sprinkler irrigation). While the variation in head loss and discharge are achieved as the water transported along the manifold. The discharge downstream from each of the outlet will effectively reduce if the outlets of manifold have regular spacing. However, the friction head loss is high and the flow rate decreased along downstream.

Commonly, design engineer uses the existing formula, for example, Hazen William formula to design a water supply system. The formula can be applied for fixing the amount of flow from each outlet. But, due to variation in the piezometric head long the pipe with multiple outlets, the flow from the outlets are not equal. In order to improve and enhance the engineering calculation of flow uniformity, the variation in flow along the pipe outlets should be reduced. Since the manifold is used in many fields, many researchers focused on the attention and effort to study it. Some of the researchers studied the mechanics of manifold analytically while others validated some formulae by using experimental data.

Howland [1] studied the design of manifold with high uniformity. Hazen-William formula was used for computing the variation of friction head loss along with manifolds [2, 3]. Mohammed et al. [4] highlighted that the Darcy-Weisbach equation is more accurate than Hazen-William formula particularly in the computation of flow distribution from the pipe with multiple outlets. Many formulae for computing friction head loss along the manifolds were proposed [3, 5, 6] and the computations of friction head loss are used for determining the variation of flow rate along the pipe with multiple outlets. Christiansen [7] gave a formula for determining the head loss along with manifolds. Many studies were focused on the determination of an accurate factor called G that can be used for computing the head loss and flow variation along with manifolds [8-12]. The change in Reynolds number along the manifold length was ignored, this assumption affects the accuracy of head loss computations [13, 14].

The improvement of flow uniformity for three-lateral dividing manifold was studied numerically and experimentally [15]. Mokhtari et al. [16] studied the flow distribution from multiple outlets pipe and they found that it is depending on the inlet discharge and the Reynolds number. The uniformity of flow from manifolds used for water distribution in pumping stations was numerically studied [17, 18].

Hassan et al. [19] assessed the experimental and numerical results related to fluid flow distribution from manifolds while Alawee et al. [20] conducted experimental work to modify the design for the header that can provide significant relief of the maldistribution.

This study aims to experimentally assess the uniformity of multiple outlet pipes by using different pipe diameters, the spacing between outlets and different initial heads.

1. Material and Methods

A physical model was fabricated to simulate the flow through PVC closed-end manifold. The test rig includes 4 main components and these components are manifold with lateral pipes, valve, piezometer and water supply tank. The valve is used to control the flow in the manifold and from the manifold outlets/laterals. Four different area ratios are used with the aim to determine the relationship between area ratio and manifold uniformity. Four different manifold diameters are used and theses diameters are; 25.4 mm (1.0 inch), 38.1 mm (1.5 inch) 50.8 mm (2.0 inch) and 76.2 mm (3.0 inch). The four different combinations of manifold diameter to lateral (outlet) diameter were used to represent real cases in water distribution systems. The combination is shown in Table 1.

There is a control valve at every pipe outlet. The spacing between the lateral pipes is fixed at 1.5 m. The spacing can be altered by open or close the valve that controls the flow in it in order to change the lateral spacing. The spacing between the laterals used in this study is 1.5 m, 3.0 m, 4.5 m, 6.0 m and finally 7.5 m. During the experiments, five runs were conducted for each selected spacing. The discharge from each outlet along the manifold was measured by using a graduated cylinder and stopwatch. Opposite to the location of each outlet, there was a piezometer to measure the head at the manifold centreline. All the piezometers were fixed on a wooden board that has graduated scale. The manifold was subjected to a constant inlet water head of 1.70 m for the first run and then was changed to 2.20 m for other runs. Steel stands are provided to support with equal spacing along the length of the manifold to make sure it is on the same level. The data was collected for all runs. Figures 1 and 2 show various components of the experimental setup used in the study.

Table 1. Manifolds combination used in experiments.

Manifold diameter, mm	Lateral diameter, mm	Diameters ratio
25.400	6.000	0.240
38.100	6.000	0.160
50.800	25.400	0.500
76.200	25.400	0.330

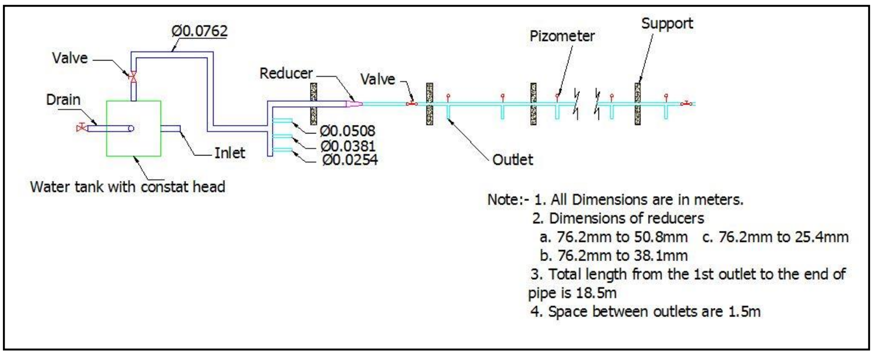

Fig. 1. Plan view of the designed test rig.

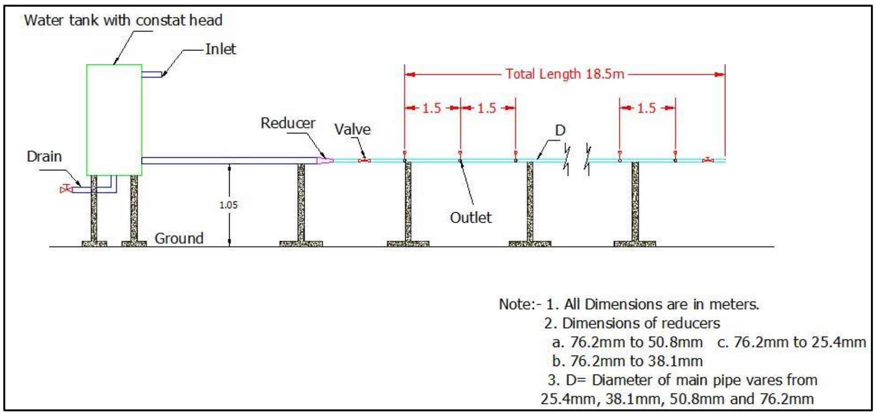

Fig. 2. Elevation view of designed test rig.

2. Results and Discussion

3.1. Physical model experimental procedure

The physical model was designed and fabrication to study the variation of flow and head along the multiple outlets PVC pipe with various spacing between outlets. The head at each outlet is measured by using piezometer. The total head loss is the difference between the reading of the first and last piezometers. Figure 3 shows the comparison of the head along pipes with multiple outlets and different spacing. The outlets spacing are 1.5 m, 3.0 m, 4.5 m, 6.0 m and 7.5 m and these spacing are used with a different combination of water levels in the supply tank (1.7 m and 2.2 m). The higher friction losses were recorded with smaller outlet spacing.

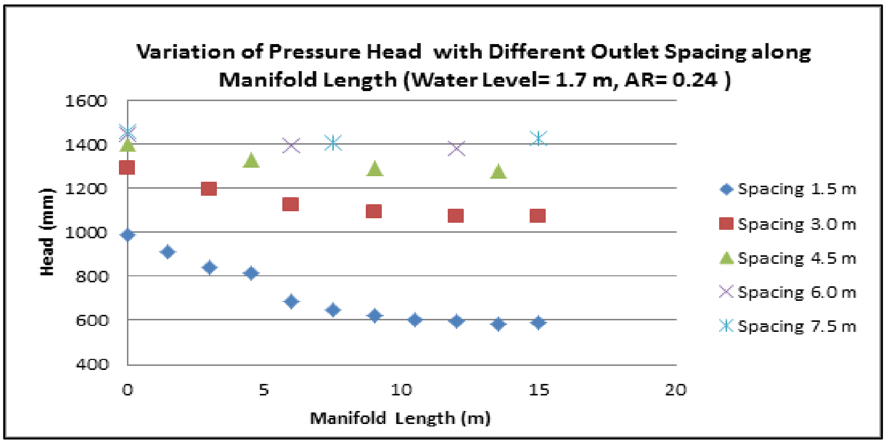

Fig. 3. Variation of pressure head with different outlet spacing.

Figure 4 shows that for fixed spacing, S/d and fixed inlet head, the smaller the ratio of the diameter, d_o/d (outlet diameter, d_o to the diameter of the main pipe, d), the smaller the total head loss has been detected. At S/d= 236.2, d_o/d = 0.24, and inlet head = 1.7 m, the total head loss was found to be 65 mm while for the same case but for *do/d* = 0.50, the head loss was 224 mm. The flow from each outlet is measured using the volumetric method. For pipe with multiple outlets, the flow is decreasing toward the end of the pipe. The total recorded head loss for the pipe with multiple outlets was found smaller compared with that recorded along the same pipe but without outlets. This comparison is made between two pipes having the same length, material and carrying the same discharging but in the first case, the water is discharged laterally from the pipe outlets while in the second case the water discharged longitudinally from pipe opening at downstream.

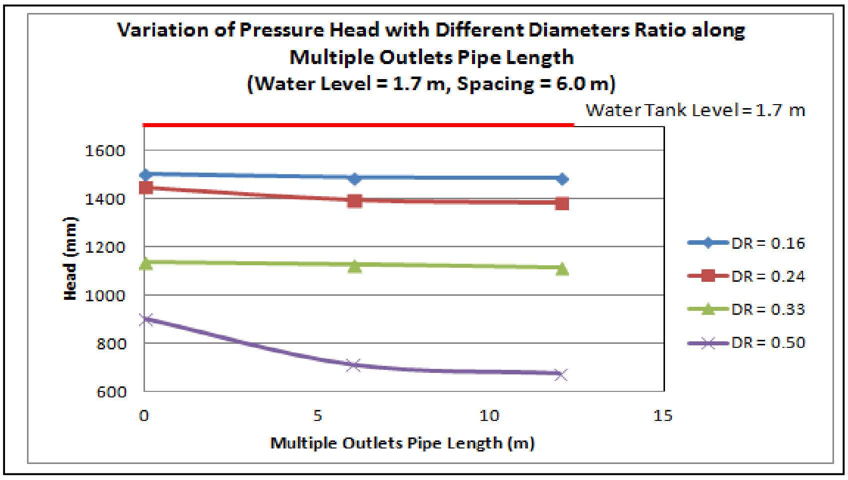

Fig. 4. Variation of pressure head with different area ratios.

3.2. Hydraulic analysis concept for manifold

Figure 5 shows the variation between normalizing head loss of H/h_f with Diameter ratio (do/*d*). The normalized head loss is the ratio between the steady water level at the supply tank. *H* and total head loss along the multiple outlet pipes, h_f. The nonlinear relationship is achieved between head ratio and the diameter ratio, DR (in general head loss, h_f increases with the increase in DR ratio). Mohammed et al. [21] described the experimental G factor by the following simple formula.

$$G = \frac{h_f}{H_f} \tag{1}$$

where H_f is the friction head loss for smooth pipe and h_f is the friction head loss in a multiple outlets pipe. Table 2 summarizes the head loss for pipe with and without outlets and the experimental *G* factor for different outlet spacing and water level in the supply tank. From these values, no clear trend in the experimental *G* factor is found. The G factor is defined as the ratio of total head loss in the pipe with multiple outlets to that in the same pipe without outlets and passing the same discharge.

Figure 6 shows the relationship between Reynolds number, Re and coefficient of friction, *f* for PVC pipe with multiple outlets. It is found that the flow in the multiple outlets PVC pipe is within the turbulent region since the values of Re were found to be from 4946 to 261897. The wide range of Re can be attributed to the decreasing flow along the length of the pipe. As a result, a value of the coefficient of friction was varied along the length of multiple outlet PVC pipe and their values are ranging from 0.0144 to 0.0377. Figure 6 shows the relationship between Reynolds number, Re and coefficient of friction, *f* for PVC pipe with multiple outlets. It is found that the flow in the multiple outlets PVC pipe is within the turbulent region since the values of Re were found to be from 4946 to 261897. The wide range of Re can be attributed to the decreasing flow along the length of the pipe. As a result, a value of the coefficient of friction, f was varied along the length of multiple outlet PVC pipe and their values are ranging from 0.0144 to 0.0377. Figure 6 shows that the coefficient of friction is following the smooth pipe curve in the Moody diagram. Uniformity coefficient can be used to describe the flow distribution from the outlets of PVC pipe.

In the present study, the effects of variables such as outlet diameter (d_o), pipe diameter (d), the spacing between outlets (S), Pipe area (A_p) and outlet area (A_o) on head loss (h_f) and flow distribution from outlets were normalized. The flow distribution from multi-pipe outlets was normalized and presented as uniformity, q_n/q_1 while the normalized head loss was presented as H/h_f. However, other governing variables were normalized and presented as S/d, d_o/d and A_p/A_o.

Table 2. Computed head loss for pipe with and without outlets and experimental *G* factor.

Pipe diameter	Water level (m)	Spacing (m)	h_f (pipe with outlets) (mm)	h_f (pipe without outlets) (mm)	Exp. *G* factor
25.400 mm	1.700	1.500	403.500	974.000	0.410
		3.000	216.000	660.000	0.330
		4.500	120.000	485.000	0.250
		6.000	65.000	235.000	0.280
	2.200	1.500	479.000	1314.000	0.360
		3.000	271.000	512.000	0.530
		4.500	125.000	412.000	0.300
		6.000	92.000	339.000	0.270
		7.500	57.500	308.000	0.190
38.100mm	1.700	1.500	165.500	1010.000	0.160
		3.000	50.000	254.000	0.200
		6.000	14.500	196.000	0.070
		7.500	12.000	145.000	0.080
	2.200	1.500	121.000	1180.000	0.100
		3.000	57.500	195.000	0.290
		6.000	12.000	145.000	0.080
		7.500	5.000	100.000	0.050
50.800mm	1.700	1.500	15.600	765.000	0.020
		3.000	408.000	747.000	0.550
		4.500	313.000	682.000	0.460
		6.000	224.000	655.000	0.340
		7.500	301.000	667.000	0.450
	2.200	1.500	25.500	1127.000	0.022
		3.000	590.000	1091.000	0.540
		6.000	675.000	1050.000	0.640
		7.500	364.000	940.000	0.390
76.200 mm	1.700	3.000	19.000	488.000	0.040
		4.500	85.500	481.500	0.180
	2.200	1.500	16.400	665.000	0.020
		3.000	30.500	644.000	0.050
		6.000	31.000	553.000	0.060

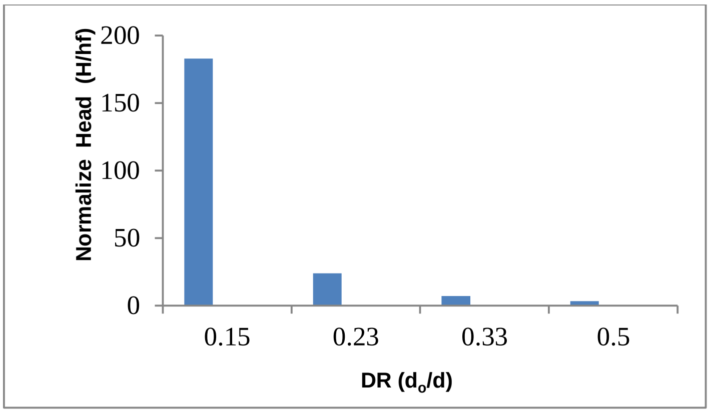

Fig. 5. Variation of head loss with different diameter ratios.

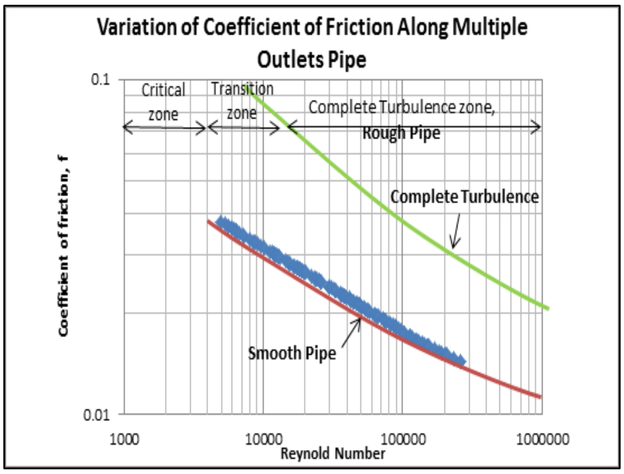

Fig. 6. Variation of coefficient of friction along the pipe with multiple outlets highlighted on Moody's diagram.

In this study, the uniformity coefficient, q_n/q_1 is defined as the ratio between last outlet discharge, q_n to first outlet discharge, q_1 [22]. Figure 7 and Table 3 show the variation of uniformity coefficient with outlet spacing ratio, *S/d* when the water level at the supply tank is 2.20 m. For 2.20 m water level at the supply tank, the uniformity coefficient varies from 0.651 to 0.953. The flow in multiple outlets pipe is nearly uniform at large values of *S/d*. For different area ratio and same initial head, the lowest uniformity coefficient is found to occur with the smallest spacing ratio. While the maximum uniformity is found to occur with the higher spacing. Figure 8 shows the variation between uniformity coefficient, q_n/q_1 and area ratio (Area of the main pipe, A_p to the area of the outlet, A_o), A_p/A_o. For the same area ratio, the uniformity increase with increasing the *S/d*. Recently, performance assessment by geographical information system in order to diagnose and improve the pressure in the water distribution system (multi outlets pipe system) were conducted [23].

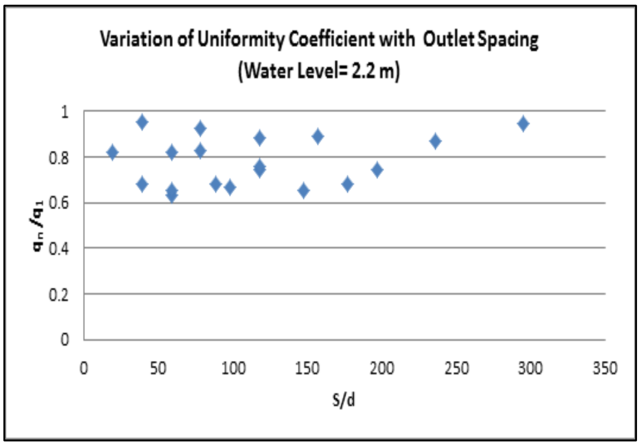

Fig. 7. Variation of uniformity coefficient with outlet spacing.

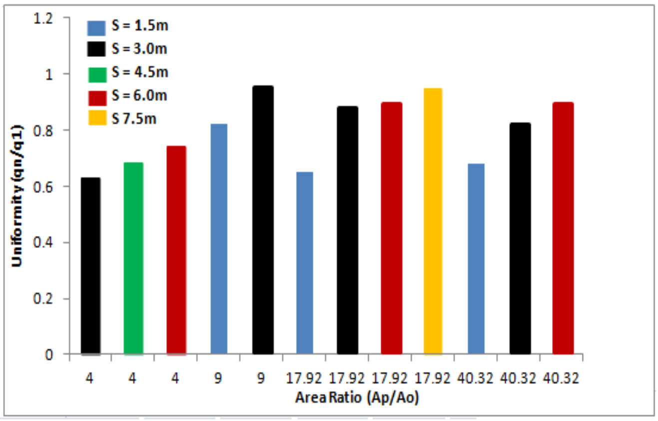

Fig. 8. Variation of uniformity coefficient with area ratios.

Table 3. Discharge distribution along multi-outlets PVC pipe when water level in supply tank was 2.20 m.

Outlet diameter	Spacing (m)	Pipe diameter (m)	*S/d*	q_1 (l/s)	q_n (l/s)	q_n/q_1
d_o = 6.000 mm	1.500	0.025	59.100	0.150	0.100	0.650
	3.000	0.025	118.10	0.150	0.130	0.890
	6.000	0.025	236.20	0.160	0.140	0.900
	7.500	0.025	295.300	0.160	0.150	0.950
d_o = 6.000 mm	1.500	0.0381	39.400	0.193	0.132	0.681
	3.000	0.0381	78.700	0.183	0.152	0.828
	6.000	0.0381	157.500	0.178	0.159	0.894
d_o = 25.400 mm	3.000	0.0508	59.100	1.859	1.174	0.631
	4.500	0.0508	88.600	2.247	1.534	0.683
	6.000	0.0508	118.100	2.370	1.757	0.742
d_o = 25.400 mm	1.500	0.0762	19.700	1.379	1.135	0.823
	3.000	0.0762	39.400	1.898	1.808	0.953

3. Conclusions

A test rig to simulate the uniformity of multiple outlets PVC pipe is designed, fabricated and operated. From this study, it is found that the inlet head, spacing between outlets and diameter ratio, *S/d* and diameter ratio, d_o/d are the governing factors affecting friction head loss and uniformity of the flow along with the multiple outlets of the PVC pipe. For the same inlet head and area ratio, results indicated increasing the uniformity with the increase in the outlet spacing. For fixed spacing, *S/d* and fixed inlet head, the smaller the ratio of the diameter, the smaller the total head loss. The relationship between head ratio with the diameter ratio was found to be non-linear (in general head loss increases with the increase in DR). The coefficient of friction in the pipe and for different discharges is found to follow the smooth pipe curve in the Moody diagram. For the same length, material, diameter and discharge, the measured friction head losses in two pipes one with outlets and the other without outlets did not show any clear relationship between them. This can be attributed to variation in outlet diameter, main pipe length and diameter, the spacing between the outlets, inlet head as well as the errors in recording the data. Therefore, the experiment *G* factor fluctuates with inlet head, pipe diameters, and outlet spacing.

Nomenclatures

A_p	Pipe area ($\pi d^2/4$), m^2
A_o	Outlet area ($\pi d_o^2/4$), m^2
d or D	Pipe diameter, m
d_o	Outlet diameter, m
f	Coefficient of friction
G	Ratio of friction head losses in pipe with and without outlets
H	Static head in the supply tank, m
Hf	Friction head loss in pipe without outlets
h_f	Friction head loss in multiple outlets pipe
q_1	Discharge from first outlet, l/s
q_n	Discharge from last outlet, l/s
Re	Reynolds number
S	Spacing between outlets, m

Abbreviations

AR	Area Ratio
DR	Diameters ratio
PVC	Plastic Polyvinyl Chloride

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