DETERMINATION AND VALIDATION OF G-FACTOR FOR PLASTIC MANIFOLDS

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ABSTRACT

G-factor is used to compute the head loss due to friction in manifolds. There are many formulae derived to compute the G-factor for manifolds. But most of these formulae were derived based on the theoretical basis with assumptions. The formulae of G-factor can be divided into two types. The first type was based on the location of the first outlet from the beginning of the manifold length while the second type was based on the end condition of the manifold (open or closed). In this study, a test rig was fabricated in order to validate formulae for G-factor. The rig consisted of an elevated tank, plastic manifolds, piezometers, and pump. Besides checking the effect of the manifold size, outlet spacing and end condition on the G-factor, the most accurate formula for computing G-factor is recommended.

Keywords: *test rig, manifold, friction head, G-factor, validation*

INTRODUCTION

Manifolds can be defined as any closed conduit that has uniform openings or branches distributed along the longitudinal centreline of conduit with a known spacing. Manifolds are normally used to distribute or collect fluids along its length and through its openings. Flow in manifold is used in many applications in various engineering fields. In civil engineering, manifolds are used mainly in water supply treatment plants, water distribution networks including irrigation networks, sewage disposal, hydroelectric power penstocks, and navigation locks. In mechanical engineering, manifolds are used in cooling systems, thermal power plants, and distribution of fuel to combustion chambers. In chemical engineering, manifolds are used in distributing and collecting chemicals to and from various plant units.

The wide range of manifold applications brings the attention of researchers around the world to study and simplify formulae governing the flow in manifolds and developing mathematical models, which can simulate real flow conditions with minimum error. The problem of flow through manifold was studied since the beginning of the last century. The pioneer who studied the manifold losses was Malishevsky [1]. He employed physical model to study the head loss through a manifold and found that the loss in a manifold is double the loss in a normal pipe of the same length but without side outlets. Christiansen [2] proposed friction head loss correction coefficient, G_c which is equivalent to the value 1/3 of the head loss for a pipe with multiple outlets.

Keller [3] studied the optimum manifold length to manifold diameter ratio on friction loss and uniformity and he proposed a ratio of 70. Dow [4] made a theoretical analysis for the flow in manifold while Horlock [5] studied the flow through a manifold using analytical and experimental techniques.

Manifold hydraulics is an important problem that was discussed by various researchers and they gave various interpretations to their findings. But in most of the published literature, the computed friction head loss was based on one estimated value for the coefficient of friction along the manifold length. This is a common assumption beside assuming equal discharge from all manifold outlets distributed with equal spacing along its length. This assumption was made by Valiantzas [6], Anwar [7], Bralts et al. [8], Yitayew [9], Wu [10], and Gillespie [11]. On the contrary, Bezdek and Solomon [12] proposed to use an explicit empirical relationship in which the coefficient of friction along the manifold can be computed from Reynolds numbers along the manifold length.

In the present study, a test rig was fabricated to determine empirical G-factor for various outlet spacing of PVC manifold. The *G*-factor obtained from the experiments was compared with the computed values using various formulae proposed by various researchers. The recorded data form the test rig will help to determine the most accurate formula of G-factor. The finding of this study is helpful because it highlights the shortcomings in current design procedure used by engineers to design waste disposal manifold, water treatment projects, water fountains, sprinkler irrigation system, and drip irrigation system.

SELECTED FORMULAE FOR G-FACTOR

The G-factor is basically proposed to relate friction head loss in a manifold to that in a pipe of same diameter and length. It is described mathematically as shown below:

$$G = \frac{H_f}{H_f^{'}} \tag{1}$$

where H_f is the friction head loss for smooth pipe with a diameter (*D*) and length (*L*) and $H_f^{'}$ is the friction head loss in a manifold with diameter (*D*) and length (*L*)

There are many formulae proposed mainly to compute G-factors for manifolds. Only limited number of these formulae was checked using field data from sprinkler irrigation lateral. So, most of the accuracy of proposed formulae for G-factor is not checked. Table 1 shows selected formulae for *G*-factor, which was checked for their accuracy using experimental data obtained from fabrication of a test rig.

Table 1: Selected G-factor formulae for G factor

Name of Researcher and Year	Formula for G-factor	Definition of Symbols
Christiansen [2]	$G = \frac{1^m + 2^m + ... + N^m}{N^{m+1}}$	*N* is number of manifold outlets, *m* is the exponent of discharge in a formula of the friction loss, *k* is index representing the successive section of pipeline length between outlets $(1 \le k \le N)$, and r is ratio of outflow.
Reddy and Apolayo [13]	$G = \frac{1}{N}\sum_{i=1}^{N}\left[1 - \frac{i^2 + i}{N^2 + N}\right]^m$	
Anwar [14]	$G = \frac{1}{N^{m+1}(1+r)^m}\sum_{k=1}^{N}(k + Nr)^m$	
Valiantzas [6]	$G = \frac{1}{m+1}\left[\left(1 + \frac{1}{2N}\right)^{m-1} - \left(\frac{1}{2N}\right)^{m+1}\right]$	

G-FACTOR FOR MANIFOLD WITH OUTLETS OF EQUAL SPACING

Figure 1 shows a segment of manifold with a typical flow case. The manifold diameter is *D* and it has n number of outlets distributed along its centerline. The total discharge entering the manifold at manifold inlet is nq while *q* is the water discharge from the manifold inlet. The water discharge is reducing toward downstream. The friction head loss between the first outlet and the second outlet is given by $(H_f)_1$ while the friction head loss between the second outlet and the third outlet is $(H_f)_2$ and for the others segments of the manifold are $(H_f)_3$, $(H_f)_4$, ...$(H_f)_{n-3}$, $(H_f)_{n-2}$, and $(H_f)_{n-1}$. The spacing between the successive outlet openings is *S*. To simplify the hydraulics of the problem, two assumptions were made, the first assumption was to consider the discharge from outlets of a manifold (*q*) to be equal from each outlet while the second assumption was to consider the coefficient of friction (λ) at various manifold segments to be equal as well.

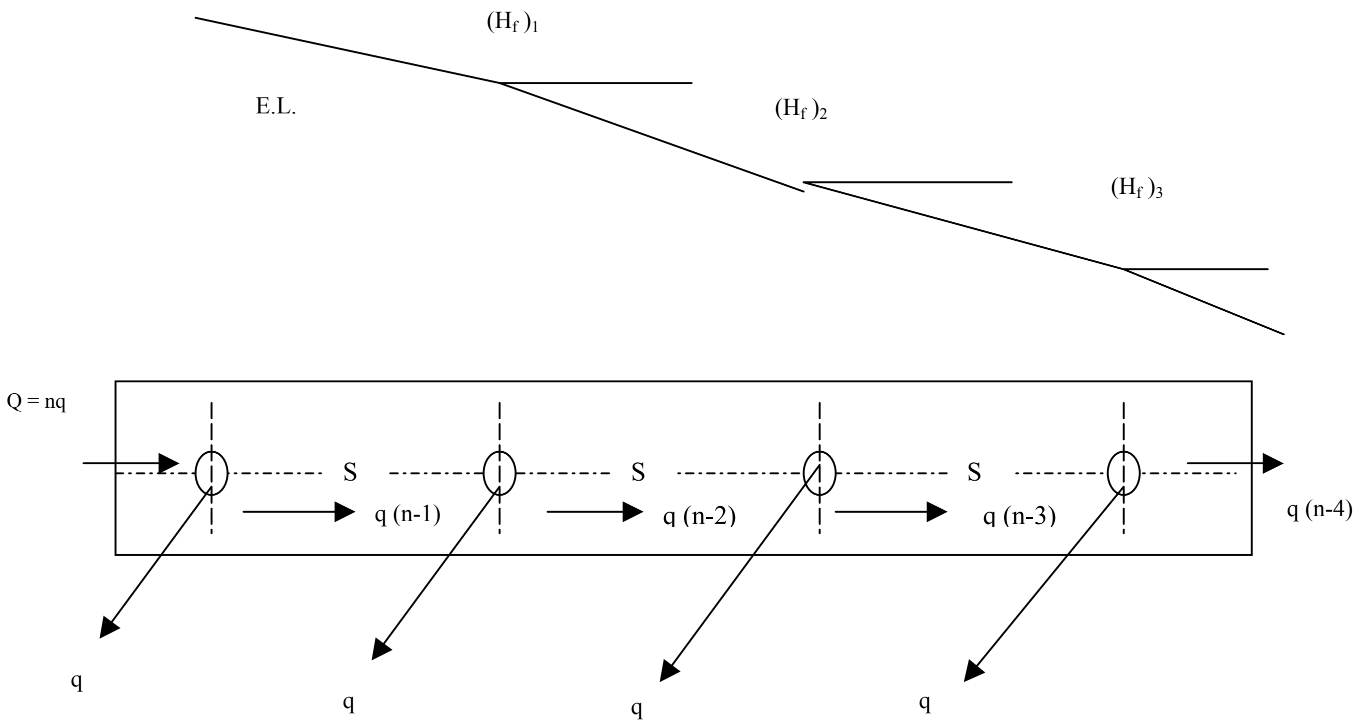

Figure 1: The variation of discharge and friction loss through a segment of a manifold

The general form of equation for computing friction loss in a pipe is shown below:

$$H_f = KD^c LQ^m \tag{2}$$

where H_f is friction head loss, K is a coefficient and equal to $8\lambda/g\pi^2$, Q is the discharge and c and m are exponents.

The total friction loss in a manifold, H'_f is equal to the summation of the friction at each segment, $(H_f)_i$ as described mathematically by the following equation.

$$(H_f)_m = \sum_{n=1}^{i=n-1} (H_f)_i \tag{3}$$

$$H'_f = KD^C S[(n-1)q]^m + KD^C S[(n-2)q]^m + ... + KD^C S[q]^m \tag{4}$$

$$H'_f = KD^C Sq^m [(n-1)^m + (n-2)^m + ... + (n-(n-1))^m] \tag{5}$$

$$H'_f = \frac{KD^C Sq^m (n^m)(n)}{n^{m+1}} [(n-1)^m + (n-2)^m + ... + (n-(n-1))^m] \tag{6}$$

After simplification we get,

$$L = nS \tag{7}$$

$$H'_f = KD^C LQ^m \frac{\sum_{i=1}^{i=n-1} (n-i)^m}{n^{m+1}} \tag{8}$$

$$H_f^{'} = H_f \frac{\sum_{i=1}^{i=n-1}(n-i)^m}{n^{m+1}} \tag{9}$$

or,

$$G = \frac{\sum_{i=1}^{i=n-1}(n-1)^m}{n^{m+1}} \tag{10}$$

As shown above, the derivation of the proposed G factor described by Equation (10) is based on stepwise computation of the friction head loss for each segment of the manifold.

THE TEST RIG AND EXPERIMENTS

The test rig used to conduct the experiments was composed of elevated water tank with overflow, plastic manifold, piezometers, control valves, pump, and steel supports. The rig was assembled at a selected site near hydraulic laboratory of the Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia. The water tank is rested on steel elevated frame. The water tank have inlet and overflow. The manifold was made of PVC pipe and holes were made in the pipe wall and from both side along its center line at a spacing of 1 m. Piezometer was fixed by using special glue at each opening of the PVC pipe wall from one side along its length. Manifold with two diameters were used and these diameters were 40 mm and 20 mm while the selected length of both manifolds was 24 m. The piezometers were collected together in three groups and fixed on a graduated board fixed to steel frames. The grouping of the piezometers facilitated the monitoring of the drop of the pressure heads along the manifold and due to the flow of water from each outlet distributed along the centreline of the manifold. Figure 2 shows a side of the test rig. The constant water head in the tank was 2.25 m for all the experiments. The overflow provided at the upper edge of the tank helps to ensure a constant water level and hence a constant water head was ensured during the experiments. Water was pumped from a nearby stream to supply the tank with water throughout the experiments.

Figure 2: The test rig

Spacing between outlets can be changed easily by closing any number of these outlets tightly. Spacing of outlets was taken as 1 m for first run and then was changed to 2 m, 3 m, 4 m, and 5 m and for each manifold diameters (40 mm and 20 mm diameters). The discharge from each outlet along the manifold was measured by using graduated cylinder and stopwatch. The temperature of the water was measured by using thermometer. Also the pressure head at each outlet was measured directly from the piezometer fixed on the graduated board. This data was collected for all runs (usually the run include testing variation of the discharge and pressure head along the manifold with specified spacing). The experiments included the manifold with closed end at downstream and also with open end at downstream.

RESULTS AND DISCUSSION

For the test rig, the determination of the experimental values of the *G* factor for the PVC manifold require the measurements of the friction head losses along both manifold and PVC pipe. However, both of them must have the same length, diameter, and discharge. The test rig is designed to be flexible, so that the manifold can be converted to a pipe by closing its outlets. In order to get a steady discharge in the pipe which is equal to that in the manifold, the gate valve at the end of the PVC pipe is regulated until its value is equal to the total measured discharges from the manifold outlets. So, the friction head losses in both manifold and pipe were measured but for different discharges. The variation of the discharge mainly depend on the spacing of the manifold outlet. In the present study, five different spacings (1m, 2 m, 3 m, 4m, and 5 m) were used. Only two diameters were used and these diameters were 40 mm and 200 mm. Figure 3 shows the variation of the experimental G factor with the manifold spacing and diameter. In this study, only four formulae for computing *G* factor were selected to check their accuracy. Also, a typical formula of G factor is derived (Equation (10)). Equation (10) was also involved in the validation process. Figures 4 and 5 show the validation of these formulae and it is clear that Equation (10) is in agreement with the experimental values of *G* factor. Statistically, the absolute error *AE* can give an idea about the accuracy of the prediction compared with the measured values as described by the following Equation:

$$AE = G_e - G_c \tag{11}$$

Where G_e is the experimental *G* factor and G_c is the computed *G* factor.

The absolute errors in the predicted G factors for flow cases were computed by using Equation (11) and the results are shown in Tables 2 and 3. Also, the test using absolute error showed that the most accurate formula for computing *G* factor is Equation (10) since it gives smallest error in its predictions.

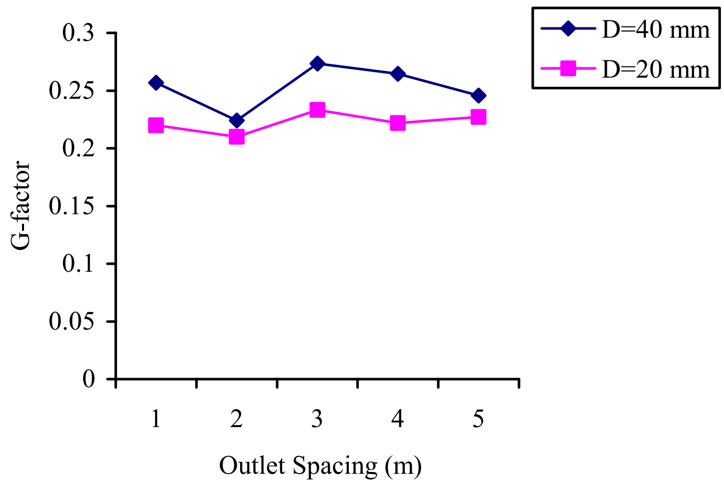

Figure 3: G-Factor for the PVC manifold with 40 mm and 20 mm diameters

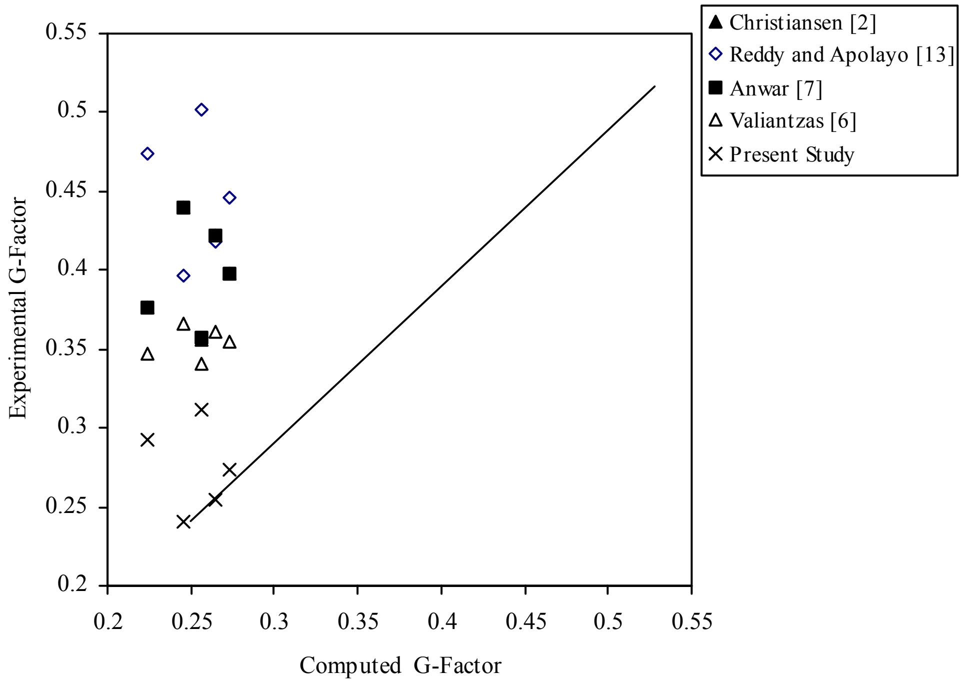

Figure 4: Validation of G-factor formulae using experimental data for 40 mm diameter manifold

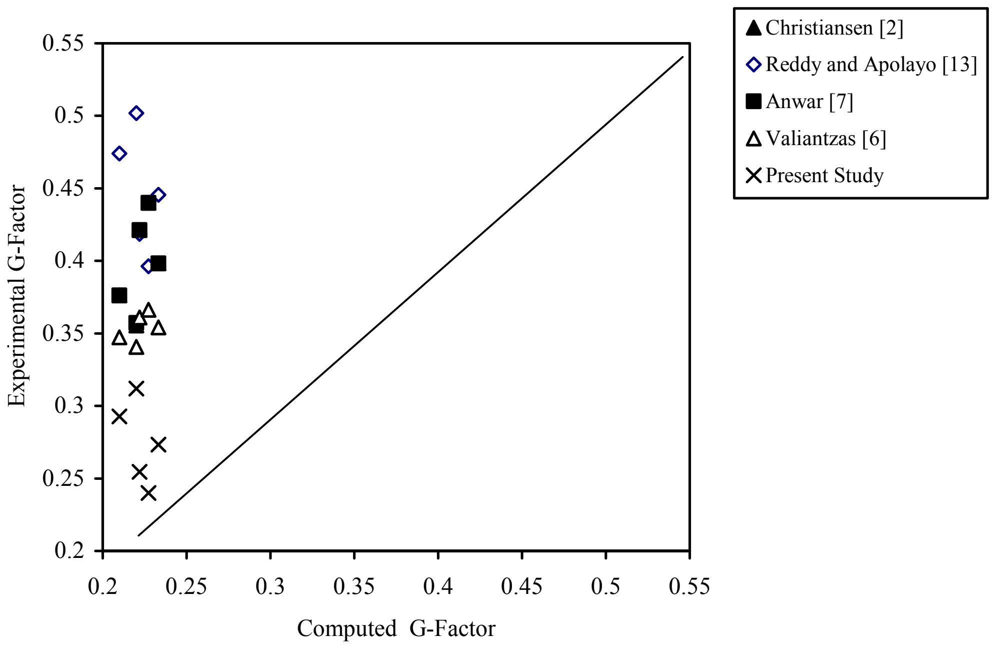

Figure 5: Validation of G-factor formulae using experimental data for 20 mm diameter manifold

Table 2: Absolute error between Experimental and computed G Factor of PVC manifold with 40 mm diameter

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Diameter	G Factor (Experiment)	G Factor (Equation (10))	Absolute error Equation (10)	G Factor (Christiansen , 1942)	Absolute error (Christiansen, 1942)	G Factor (Valiantzas, 2002)	Absolute error (Valiantzas, 2002)	G Factor from (Apolayo, 1988)	Absolute error (Apolayo, 1988)	G Factor (Anwar, 1999a)	Absolute error (Anwar 1999a)
40 mm	0.2569	0.3119	0.0550	0.3554	0.0985	0.3406	0.0837	0.5019	0.2450	0.3573	0.1004
	0.2242	0.2928	0.0686	0.3762	0.1519	0.3472	0.1230	0.4740	0.2498	0.3762	0.1520
	0.2776	0.2734	0.0042	0.3984	0.1208	0.3541	0.0765	0.4456	0.1680	0.3984	0.1208
	0.2646	0.2546	0.0099	0.4213	0.1567	0.3609	0.0963	0.4180	0.1534	0.4213	0.1567
	0.2457	0.2400	0.0057	0.4400	0.1943	0.3663	0.1206	0.3964	0.1507	0.4400	0.1943

Table 3: Absolute error between Experimental and computed G Factor of PVC manifold with 20 mm diameter

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Diameter	G Factor Experiments	G Factor (Equation (10))	Absolute error (Equation (10))	G Factor (Christiansen , 1942)	Absolute error (Christiansen, 1942)	G Factor Valiantzas(2 002)	Absolute error (Valiantzas, 2002)	G Factor (Apolayo, 1988)	Absolute error (Apolayo, 1988)	G Factor (Anwar 1999a)	Absolute error (Anwar, 1999a)
20 mm	0.21	0.3119	0.102	0.3554	0.145	0.3406	0.131	0.5019	0.292	0.3573	0.147
	0..22	0.2928	0.073	0.3762	0.156	0.3472	0.127	0.4740	0.254	0.3762	0.156
	0.2333	0.2734	0.0402	0.3984	0.1652	0.3541	0.1208	0.4456	0.2123	0.3984	0.1651
	0.2220	0.2546	0.0326	0.4213	0.1993	0.3609	0.1389	0.4180	0.1960	0.4213	0.1993
	0.2272	0.2400	0.0128	0.4400	0.2128	0.3663	0.1391	0.3964	0.1692	0.4400	0.2128

CONCLUSION

The average value of the G factor for PVC manifold with a 40 mm diameter is 0.253 while that for manifold with 20 mm diameter is 0.222. Validation of selected formulae proposed by various researches to compute G factor for manifold showed that the most accurate one is Equation (10). This is supported by the computation of the absolute error using Equation (11). The experimental data used for computing the absolute error is collected from the test rig.

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