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Physical Simulation for the Flow in Straight and Rectangular Loop Manifolds

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ABSTRACT

The flow in a manifolds considered as an advanced problem in hydraulic engineering applications. The objectives of this study are to determine; the uniformity qn/q1 (ratio of the discharge at last outlet, qn to the discharge at first outlet, q_1) and total head losses of the flow along straight and rectangular loop manifolds with different flow conditions. The straight pipes were with 18 m and 19 m long and with of 25.4 mm (1.0 in) in diameter each. While, the rectangular close loop configuration was with length of 19 m and with diameter of 25.4 mm (1.0 in) also. Constant head in the supply tank was used and the head is 2.10 m. It is found that outlets spacing and manifold configuration are the main factors affecting the uniformity of flow distribution and friction head losses along manifolds. For large value of outlets spacing, the uniformity coefficient (q_n/q_1) was found with greatest value of 0.96. Thus, the flow distribution improves with bigger spacing between outlets along manifold. For same manifold length, diameter, inlet head and spacing between outlets (S/L=0.079), the uniformity coefficient was found 0.881 or 88.1% for straight manifold and 0.926 for rectangular loop manifold. From the experimental data, a better uniformity is obtained from the rectangular loop manifold, this is because the friction head loss in rectangular loop manifold was lower than that in straight manifold. The lowest of total head losses was found with greatest outlet spacing along manifold, while the highest of total head losses was found with smallest outlets spacing along manifold. And, the lowest of total head loss was found with the rectangular manifold, while the highest of total head loss was found with the straight manifold.

Keywords: Coefficient of friction, distribution flow, head loss, multiple outlets, uniformity, rectangular loop manifold

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المحاكاة الفيزيائية للتدفق في الانابيب المتشعبة المستقيمة و المستطيلة الحلقية

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الخلاصة

يعد الجريان في الانابيب المتفرعة أحد المشاكل المتقدمة في تطبيقات الهندسة الهيدروليكية. تهدف هذه الدراسة الى ايجاد انتظامية تدفق الجريان (q_n/q_1) (النسبة بين كمية التصريف من الفتحة الاخيرة إلى كمية التصريف من الفتحة الاولى) وايجاد إجمالي خسائر الضغط للجريان على طول الانابيب المتشعبة المستقيمة والمستطيلة الحلقية عند شروط جريان مختلفة. اطوال الانابيب المستخدمة كانت 18 متر و19 متر وبقطر 25.4 ملمتر. استخدم عمود ماء ثابت الارتفاع في خزان تجهيز الماء عند 2.10 متر. بينت النتائج ان المسافة بين الفتحات الجانبية على طول الانبوب المتفرع وشكل الانبوب تعد من العوامل الرئيسة التي تؤثر على انتظامية توزيع الجريان وخسائر الضغط بسبب الاحتكاك عل طول الانبوب. بالنسبة للمسافات الكبيرة بين الفتحات الجانبية، كما وجد ان معامل الانتظامية (q_n/q_1) يمتلك أكبر قيمة 0.96، لذلك يتحسن توزيع الجريان على طول الانبوب المتشعب كلما زادت المسافة بين الفتحات الجانبية. عند استخدام انابيب بنفس الطول والقطر والضغط الداخل والتباعد بين الفتحات الجانبية (S = 1.5 متر)، وجد ان معامل الانتظامية (0.881) للأنبوب المتشعب المستقيم و(0.926) للأنبوب المتشعب المستطيل الحلقي. ألقد وجد ان فضل توزيع للجريان في الانبوب المتفرع المستطيل الحلقي وذلك لأن خسائر الضغط بسبب الاحتكاك في الانبوب المتفرع المستطيل الحلقي كانت أقل بالمقارنة مع الانبوب المتفرع المستقيم. كما وجد ايضا ان اقل قيمة لأجمالي خسائر الضغط كانت مع أكبر مسافة بين الفتحات الجانبية على طول الانبوب المتفرع، بينما وجدت اعلى قيمة للخسائر مع أصغر مسافة بين الفتحات الجانبية. وكذلك وجد ان اقل قيمة لأجمالي خسائر الضغط كانت في الانبوب المستطيل الحلقي بينما اعلى قيمة كانت في الانبوب المستقيم.

الكلمات الرئيسية: الانبوب المتفرع، خسائر الارتفاع، الانتظامية، معامل الاحتكاك، الانبوب المتفرع المستطيل.

1. INTRODUCTION

A manifold is a straight pipe with lateral openings along its centerline. Due to inflow or outflow of fluid through the lateral openings of the manifold, the flow along its centerline is either increasing or decreasing. Manifolds have many applications such as; irrigation systems, flow distribution in water and waste water systems and treatment plants, piping systems of pumping stations, industrial plants and distribution of fuel system **(Alawee, et al., 2020)**.

Manifolds are categorized into dividing, combining, parallel, and reverse flow **(Gandhi, et al., 2012)**. Many researchers around the world studied the phenomenon of water flow in a manifold. Some of the researchers studied the problems of flow distribution in manifold analytically while others used some formulae and validated by using experimental data.

(Howland, 1953) conducted a study to obtain a best uniformity of flow from the lateral outlets along manifold and proposed an equation that takes into account the variations of head/pressure along a manifold. **(Mohammed, et al., 2003)** showed that the Darcy-Weisbach formula is more accurate than Hazen-William formula in the computations of flow distribution in manifolds. **(Anwar, 1999b)** and **(Valiantzas, 2002a)** proposed many formulae to compute friction losses along manifold and determine the variation of flow distribution. **(Keller and Bliesner, 1990)** assumed in their study Reynolds number and the coefficient of friction in manifold are constant. **(Mokhtari, et al., 1997)** concluded the distribution of flow along manifold depending on the

Reynolds number and the inlet velocity. **(Vallesquino and Luque-Escamilla, 2002)** proposed useful method to the hydraulic computations of manifold with different diameters of header, flow regimes and pipe slope. **(Koh, et al., 2003)** showed in their study that the diameter, length and shape of manifold have significant effect on pressure and flow distributions along manifold. **(Mostafa, 2004)** presented a study showed the effect of the inlet flow rate change and outlets spacing change on the uniformity of flow distribution in manifold.

(Provenzano and Pumo, 2004) showed that the variations of flow in a manifold due to variations of head losses along the manifold and the flow variations depend on manufacturing variability of pipe and water temperature.

(Maharudrayya, et al., 2005) showed that the flow distribution in manifold depends on the manifold dimensions, the channel dimensions and the spacing between the parallel channels. **(Yildirim, 2006)** proposed suitable equations for designing manifolds, that can be applied for different types of outlets and different flow regimes. **(Hassan, et al., 2015)** illustrated in their study the parameters which effect the flow distribution along manifold. These parameters included the area ratio and spacing between outlets. **(Tong, et al., 2009)** showed in their study that, enlargement of the area of the manifold, changing the areas of the lateral channels and use manifold with tapered longitudinal section are most effective factors for the attainment of uniformity of flow distribution in manifold.

(Sadeghi and Peters, 2011) presented a study to develop factors that used to compute the friction loss and calculate the inlet pressure in horizontal tapered manifold. **(Sadeghi, et al., 2012)** conducted a study to calculate the friction head loss and sizing of tapered laterals pipeline of sprinkler and trickle irrigation systems. **(Hassan, et al., 2014a)** conducted an experimental and numerical study on a manifold with tapered and circular longitudinal section to determine the uniformity of flow distribution along manifold. They found a maldistribution in flow rates from manifold outlets for circular cross-section while nearly uniform distribution of flow for tapered cross-section.

(Alawee, et al., 2019) conducted tests on a physical model to study the variation of flow distribution and variation of total head loss along manifold. They found that spacing between outlets, diameter of outlets and header and the inlet head were main factors affecting uniformity of flow and total friction head loss along the manifold.

(Alawee, et al., 2020) studied the variation of the coefficient of friction and total friction head losses along a manifold. They concluded that, the values of the coefficient of friction are affected by the decreasing discharge towards the dead end of manifold and friction head losses increase with the decrease in outlets spacing along manifold and the increase in area ratio A_o/A (ratio between cross-section area of outlet, A_o to cross-section area of manifold -, A).

In this study, a physical model was designed and fabricated in order to evaluate the uniformity of flow distribution and the total friction head losses along straight and rectangular loop manifolds.

2. MATERIAL AND METHODS

The physical model was built at a selected site in the training and workshops center, University of Technology, Baghdad, Iraq. **Fig. 1** show three-dimensional view of the physical model of the manifold system used in the study. Also, **Fig. 2** show the physical model with its various components after fabrication. The main parts of the test rig are the water supply tank with overflow, storage tank, polyvinyl chloride (PVC) pipes, small tubes, steel supports, pumps and valves.

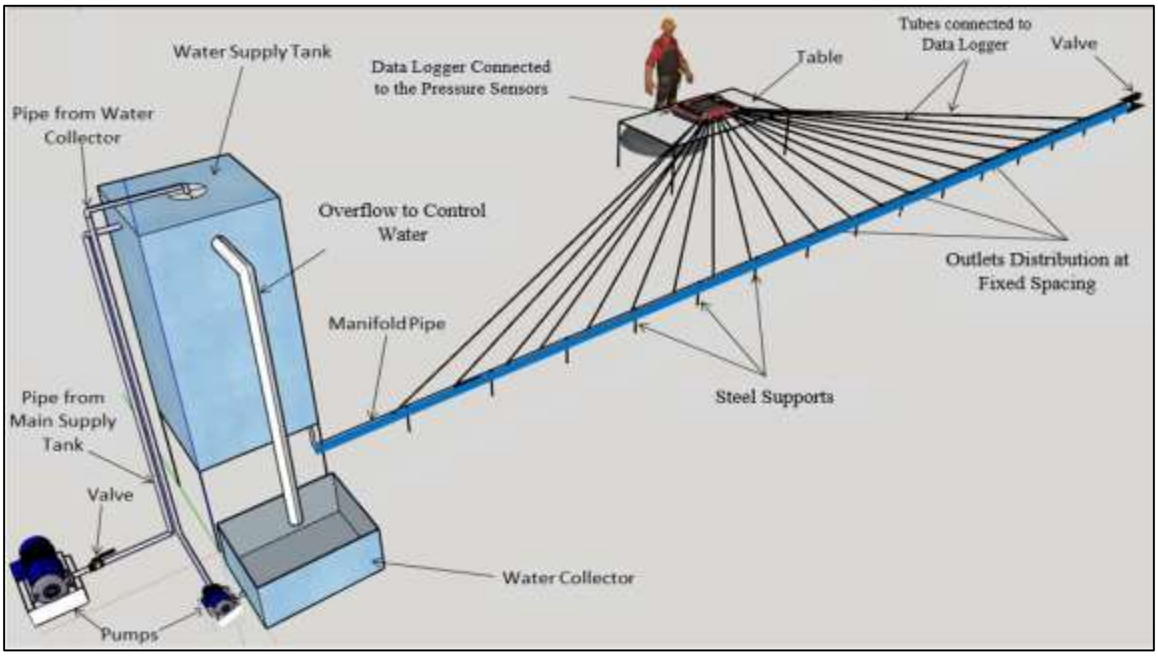

Figure 1. 3-D schematic drawing for the test rig used for conducting the experiments.

Figure 2. Plate of the test rig.

The manifold of a 25.4 mm (1.0 in) diameter was connected to the water supply tank and laid on steel supports at intervals of 1.15 m. Two models of dividing manifolds are used during the experiments by straight manifold and rectangular closed loop manifold. The lengths of manifolds were 18 m and 19 m. The straight manifolds were with different spacing between outlets in order to study their effect on the uniformity of flow distribution and the coefficient of friction along manifolds.

The spacing between the outlets distributed along the manifold were 0.75 m, 1.5 m, 2 m, 2.5 m and 3 m. While rectangular closed loop manifold was with of 1.5 m outlets spacing. For an experiment run with a manifold length of 18 m, diameter of 25.4 mm, outlet diameter of 5 mm and inlet head of 2.76 m, the total maximum discharge was 1.21 L/s for outlets spacing of 0.75 m and total minimum discharge was 0.52 L/s for outlets spacing of 3 m. Two valves were placed and glued at the beginning and end of the pipe to control of flow.

3. FLOW LOOP AND MEASURING DEVICES

The constant-level supply tank was with a 3.91 m^3 capacity and used to supply water to the test rig. Its dimensions are 2.5 m ×1.25 m ×1.25 m (height × length × width). An overflow pipe is installed at a height of 2.10 m from the tank base and it has 101.6 mm diameter and 2.5 m length to keep the water level inside the tank constant during the experiments. The water from overflow pipe was collected in a small ground tank with a dimensions of 0.5 m ×1 m ×1 m (height × length × width) and the tank was connected to a pump. Collect water in the tank was pumped back to the supply tank by outlet pipe has 12.7 mm diameter and control valve. This combination ensured a good water circulation system. In this study, inlet head was 2.10 m. The discharge from the outlets was measured using the volumetric method (collecting ontainer have dimensions 30 cm for height, length and width, digital balance and stopwatch). Piezometers were used to measure the head of water at each outlet of the manifold. The piezometers were used to calibrate the sensors used to measure the pressure at each outlet of the manifold. The sensors were used to measure the instantaneous pressure at each outlet of the manifold.

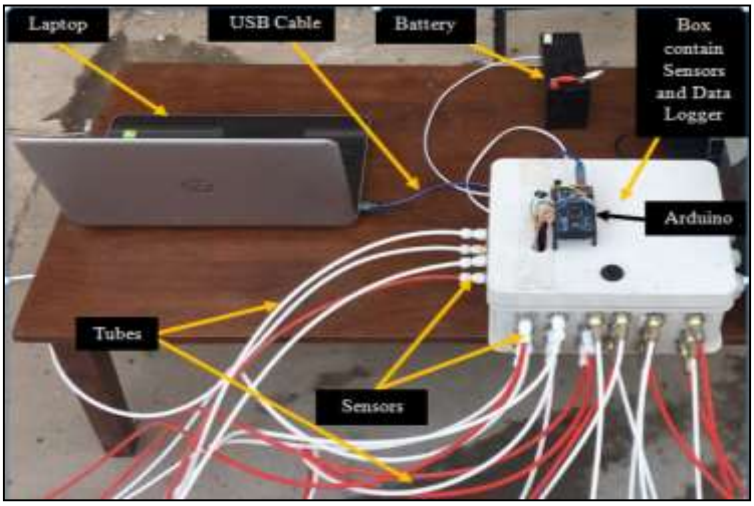

Figure 3. The connection of manifold outlets, data logger and computer to sensors

The sensors were linked with tubes of 6 mm diameter distributed along the centerline of the manifold at location opposite to the outlets in order to measure the pressure/head at the outlet. The pressure sensors were connected to a data logger and the later was linked to a computer as shown in **Fig. 3**. A special program which convert the readings of each sensors with time to a digital reading and it displayed on the computer screen. Each sensor can read a pressure between 0 to 207 kPa. The total number of sensors were 22 with an accuracy of 3%. In all experiments pressure measurements by the sensors were counter checked by using piezometers. Firstily the head/pressure at each outlets of the manifold was measured by sensors and then by piezometers. This procedure was used to calibrate the sensors used in pressure measurements. The recorded head/pressure by sensors at each outlet was the average of all recorded readings during the experiment run, while the recorded head/pressure by piezometers at each outlet was the average of three recorded readings.

4. RESULTS AND DISCUSSION

The physical model was designed and fabricated to study the variation of flow and pressure along the straight manifold with different outlets spacing and compared with the rectangular loop manifold. **Fig. 4** shows a comparison of the flow distributions along a straight manifold with a diameter of 25.4 mm and length of 18 m for different outlet spacing. The manifold was subjected to inlet head of 2.76 m. The spacing between outlets were 0.75 m, 1.5 m, 2 m, 2.5 m and 3 m. When the spacing between outlets of straight manifold was 3 m, the calculated uniformity was found to be 84% while the uniformity was increased to 96.5% when the spacing between outlets was increased to 4 folds. For smaller spacing, the number of outlets increased which resulted in greater discharge and greater head loss.

Fig. 5 shows a comparison of the flow distribution along a straight and rectangular loop manifolds having the same length, diameter, spacing between outlets (1.5 m) and inlet pressure.

The uniformity of the flow in rectangular loop manifold was 95% while that in the straight manifold was 85% and this can be attributed to the gain in head in the loop rectangular manifold.

Fig. 6 shows the variation between the normalized discharge, q_i/Q_T (discharge from outlet, q_i to the total discharge, Q_T) and length ratio, L_i/L_T (distance of any outlet, L_i to total length of a manifold, L_T) along the straight manifold. **Fig. 7** shows the variation between the normalized discharge, q_i/Q_T with the length ratio, L_i/L_T along the straight and rectangular loop manifolds having the same size and dimensions. This normalized relations are useful for the design engineers. The results show that the flow distribution along a straight manifold was affected by the spacing between the outlets. For straight manifold, the smallest outlets spacing (0.75 m) gave the highest total discharge (1.2091 l/sec) while the highest outlets spacing (3 m) gave the lowest total discharge (0.51583 l/sec) because the number of outlets are increased.To calculate the uniformity of the flow along a manifold, there were many formulae proposed by previous researchers for this purpose. In this study, the uniformity coefficient (q_n/q_1) was used to describe the uniformity of flow along manifolds and it is defined as the ratio of the discharge from the last outlet, q_n to the discharge from the first outlet, q_1. The best uniform distribution of flow can be obtained when the value of the uniformity coefficient equal or close to 1 **(Hassan, et al., 2014b)**.

Table 1 and **Fig. 8** show the variation of uniformity coefficient with spacing ratio, S/d (ratio between outlets spacing, S to manifold diameter, d). The uniformity coefficient was found to vary from 0.849 to 0.96 for the straight manifold with inlet head of 2.76 m and outlets spacing of 0.75 m, 1.5 m, 2 m, 2.5 m and 3 m. For large value of spacing ratio, S/d (S=3 m), the uniformity coefficient was found with greatest value of 0.96. Thus, the flow distribution improves with larger outlet spacing.

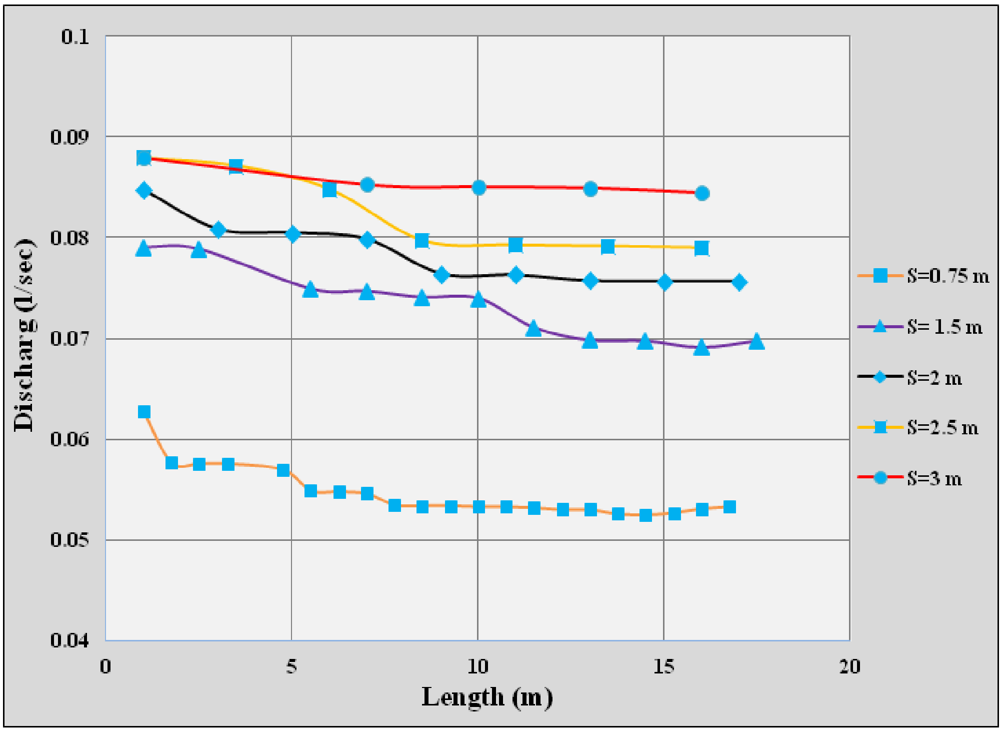

Figure 4. Variation of flow along straigh manifold with different outlets spacing.

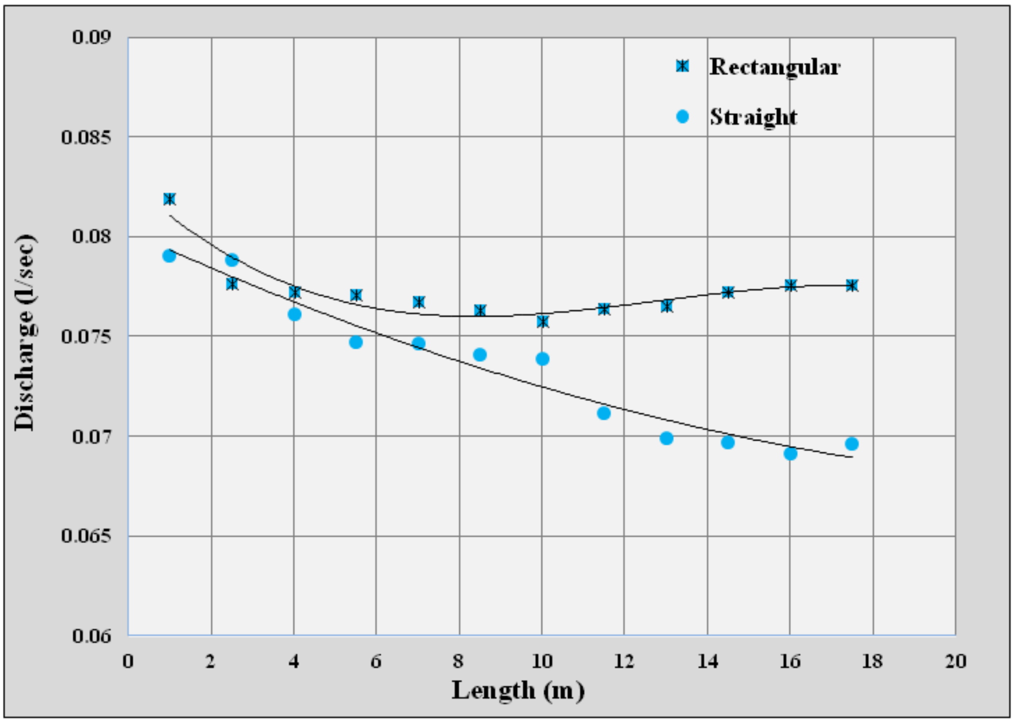

Figure 5. Variation of flow along straight and rectangular loop manifolds for outlet spacing of 1.5 m.

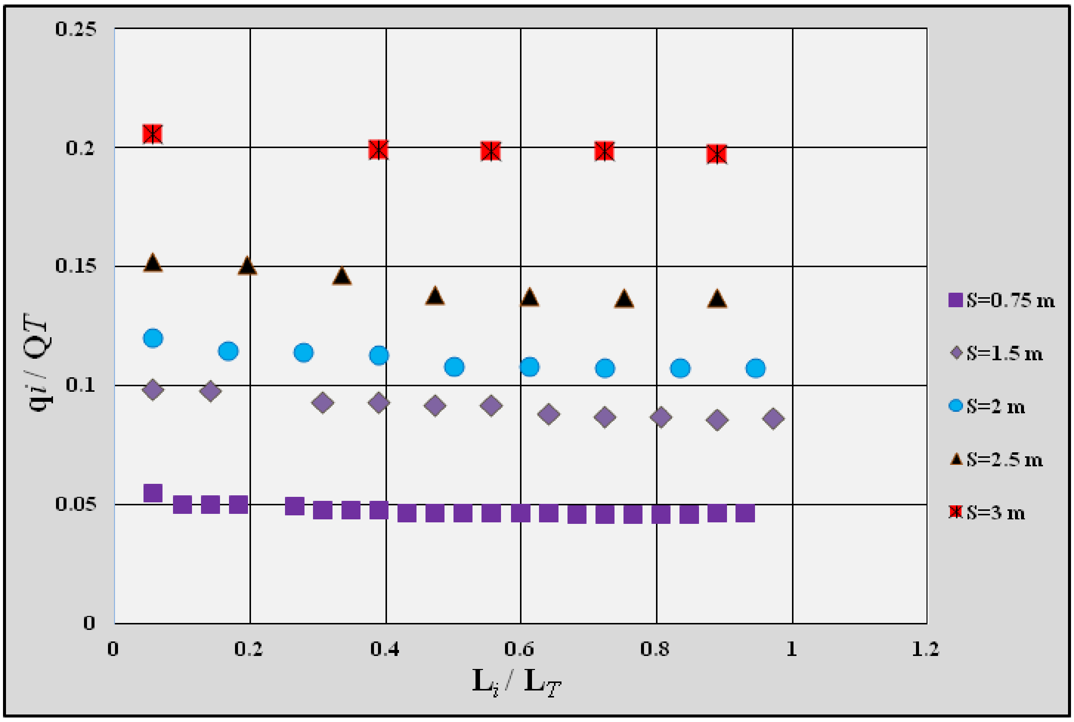

Figure 6. Variation of the normalized discharge with the straight manifold length for different outlets spacing

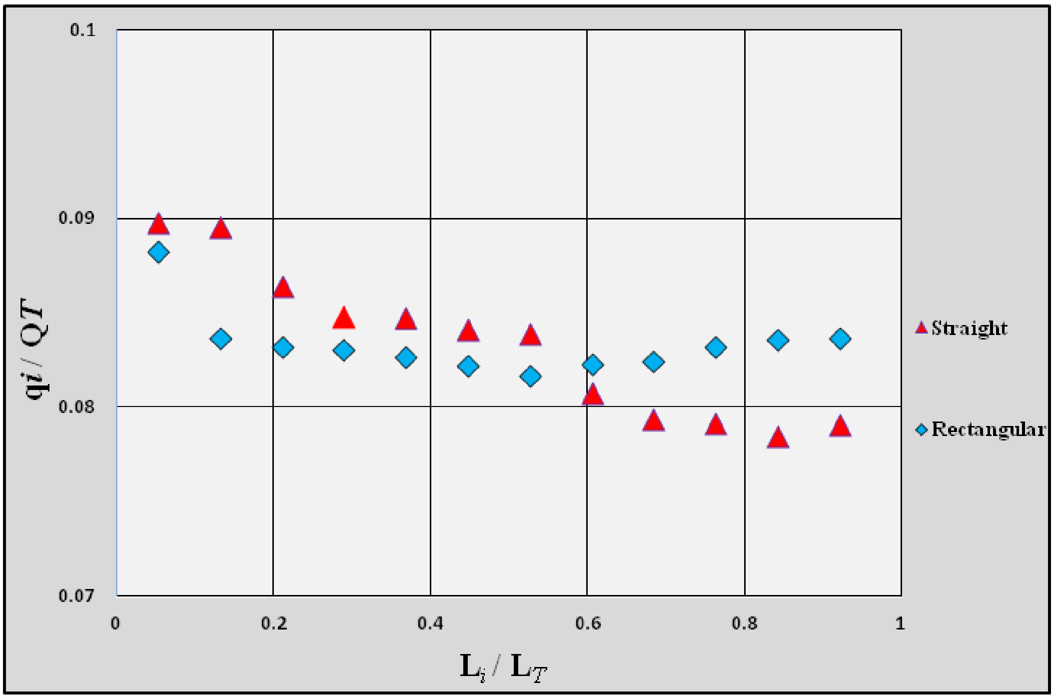

Figure 7. Variation of the normalized discharge along straight and rectangular loop manifolds for outlets spacing of 1.5 m.

Table 1. Uniformity coefficient for 2.76 m inlet head.

Manifold Configuration	L m	S m	d mm	S/d	q_1 l/sec	q_n l/sec	q_n/q_1
Straight	18	0.75	25.4	30	0.063	0.053	0.849
Straight	18	1.5	25.4	59	0.079	0.070	0.882
Straight	18	2	25.4	79	0.085	0.076	0.893
Straight	18	2.5	25.4	98	0.088	0.079	0.899
Straight	18	3	25.4	118	0.088	0.084	0.960
Straight	19	1.5	25.4	59	0.079	0.070	0.881
Rectangular loop	19	1.5	25.4	59	0.082	0.076	0.926

Table 1 and **Fig. 9** show the variation of uniformity coefficient with the spacing ratio, S/d for straight and rectangular loop manifolds under inlet head of 2.76 m and outlets spacing of 1.5 m. For same manifold length, diameter, inlet head and constant spacing ratio, S/d=59 (S=1.5 m), the uniformity coefficient was found to be the lowest, $q_n/q_1=0.881$ for straight manifold and to be the greatest $q_n/q_1=0.926$ for rectangular loop manifold. This is because the friction head loss in rectangular loop manifold was lower than that in straight manifold **(Hassan, et al., 2014c)**. The looping of the manifold reduced the total head loss in the manifold which reduced the difference in discharge between the first and last outlets (increased the uniformity). The ratio q/Q (average outlet discharge/ total discharge) was approximately 4% when the number of outlets were 24, however, when the number of outlets was reduced to 12, the ratio was 8%. When the number of outlets change, the friction head loss was affected which affects the value of total discharge.

In all experiments, two methods were used to measure the pressure at each outlets of the manifolds, the first method was using sensors while the second was achieved by using piezometers. This procedure was used to check the accuracy of the sensors and also to make sure that the head were correctly measured **(Hassan, et al., 2019)**.

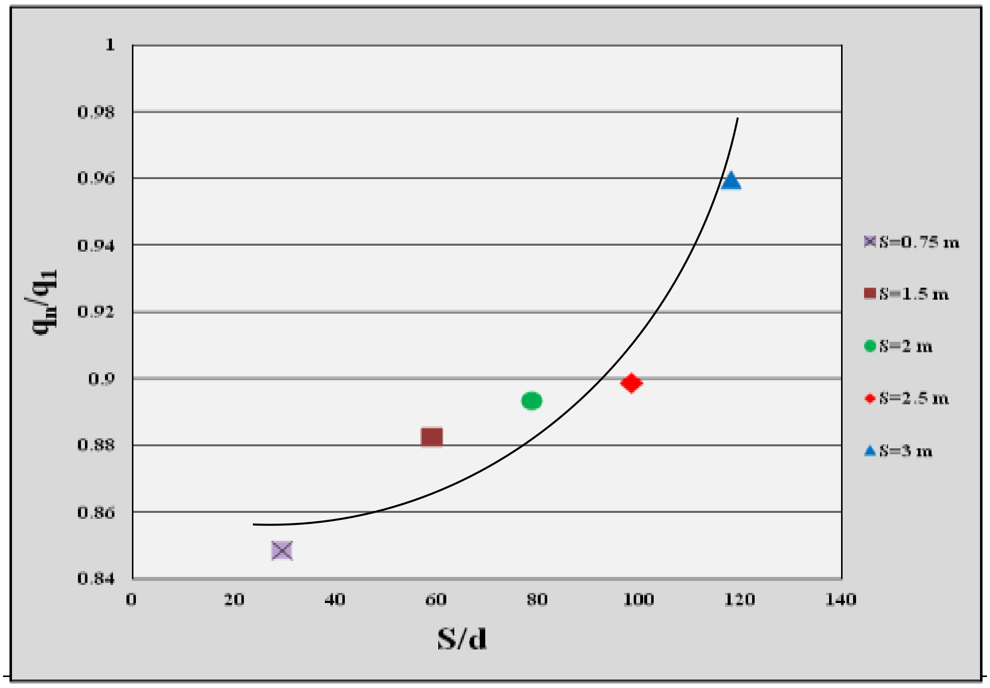

Figure 8. Variation of uniformity coefficient with the spacing ratio for straight manifold

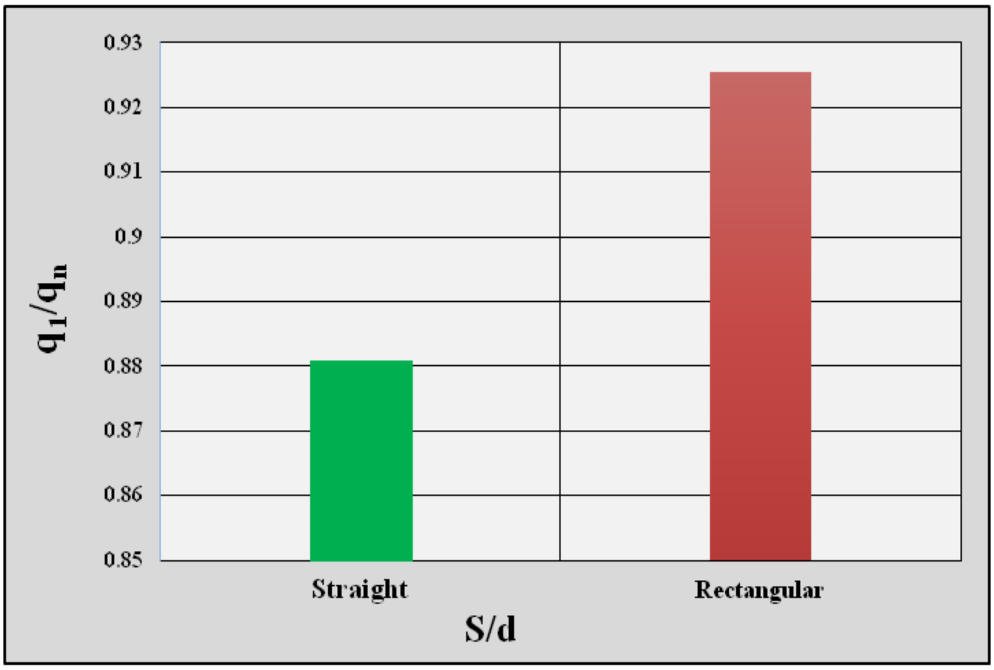

Figure 9. Variation of uniformity coefficient with various manifold configuration for spacing of 1.5 m

Fig. 10 and **11** shows a sample of sensors and piezometers readings respectively for a straight manifold with outlets spacing of 3 m. From the show results , it can be seen that the difference between sensors and piezometers readings was within 3% and it is within the permissible range approved by the sensor's manufacturer [Alawee, et al., 2019]. The error in the sensor reading can be attributed to the ambient temperature and to the sensitivity of the sensors to the various factors such as fluctuations in water level in the supply tank. Consequently, it can be concluded that, the use of the sensors in pressure measurements are sufficient and successful in terms of time and data management and control.

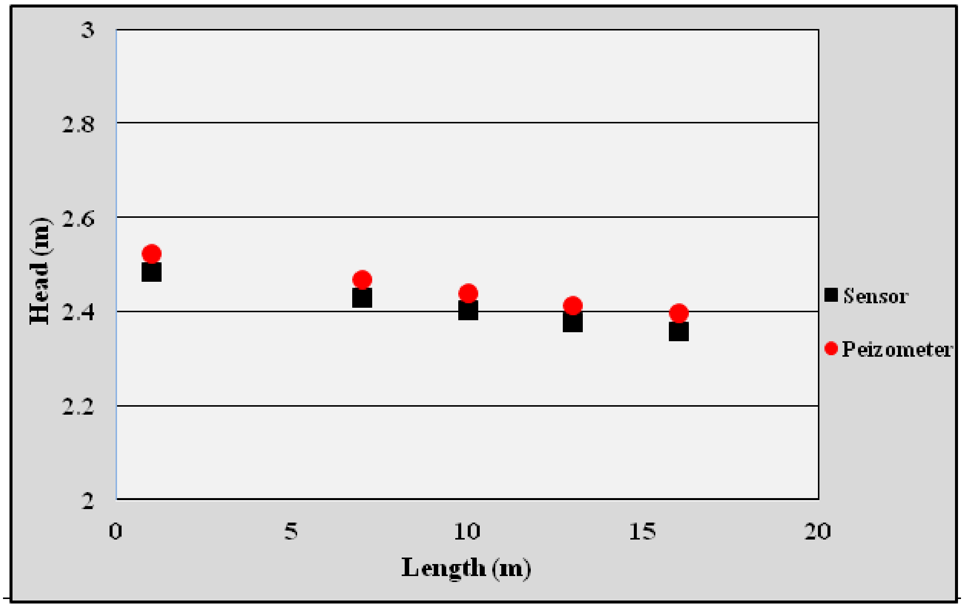

Figure 10. Comparison between sensors and piezometers readings for manifold with outlet spacing of 3 m

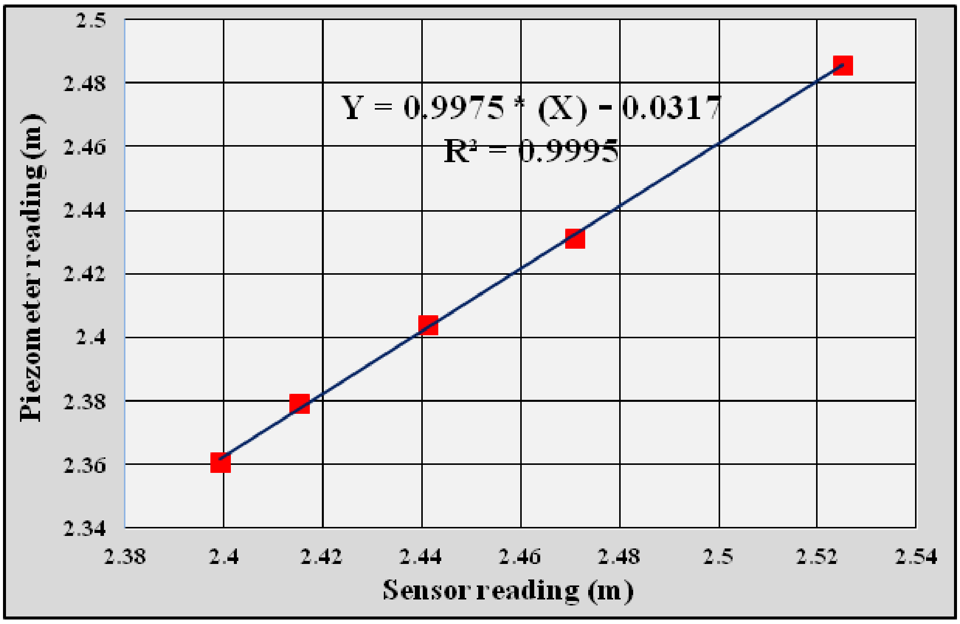

Figure 11. Sensors readings versus the piezometer readings for the case of manifold with outlet spacing of 3 m

Fig. 12 shows the variation of pressure along a straight manifold with different outlets spacing (0.75 m, 1.5 m, 2 m, 2.5 m and 3 m). **Fig. 13** shows the variation of pressure along a straight and rectangular loop manifolds with outlets spacing, 1.5 m. The head at the first outlet and at the last outlet were different and difference between these heads was used to determine the total head loss along the manifold. For example, the total head loss along the straight manifold was 425% greater than that in the loop rectangular manifold. **Fig. 14** shows the effect of outlets spacing (0.75 m, 1.5 m, 2 m, 2.5 m and 3 m) on total head loss along a straight manifold with inlet head of 2.76 m. Depending of the outlet spacing, the total head loss was varied from 0.125 m to 0.489 m. For greatest outlets spacing, S=3 m, the total head loss was the lowest (0.125 m) and vice versa for smallest outlets spacing, S=0.75 m, the total head loss was the greatest (0.489 m). This is because the total discharges from the manifold outlets with spacing of 3 m was much less than the total discharges from the manifold outlets with spacing of 0.75m. For the flow in pipes, greater discharge usually results higher head loss.

For loop rectangular manifold with outlets spacing of S=1.5 m, the total head loss was found to be 0.085 m while the total head loss in straight manifold was found to be 0.407 m.

Fig. 15 shows the variation between the normalized head loss, h_f/H (ratio between the total head loss along the manifold, h_f to the inlet head, H) for various spacing ratio, S/d. For the straight manifold, the normalized head loss h_f/H was varied from 0.045 to 0.177. For greatest spacing ratio, S/d=118 (S=3 m), the normalized head loss was found to be the lowest (h_f/H=0.045) and vice versa for lowest S/d=30 (S=0.75 m), the normalized head loss was the greatest (h_f/H= 0.177).

For the same spacing ratio, S/d (S=1.5 m), the value of normalized head loss for loop rectangular manifold, h_f/H was found to be 0.031 while that for straight manifold was found to be 0.148.

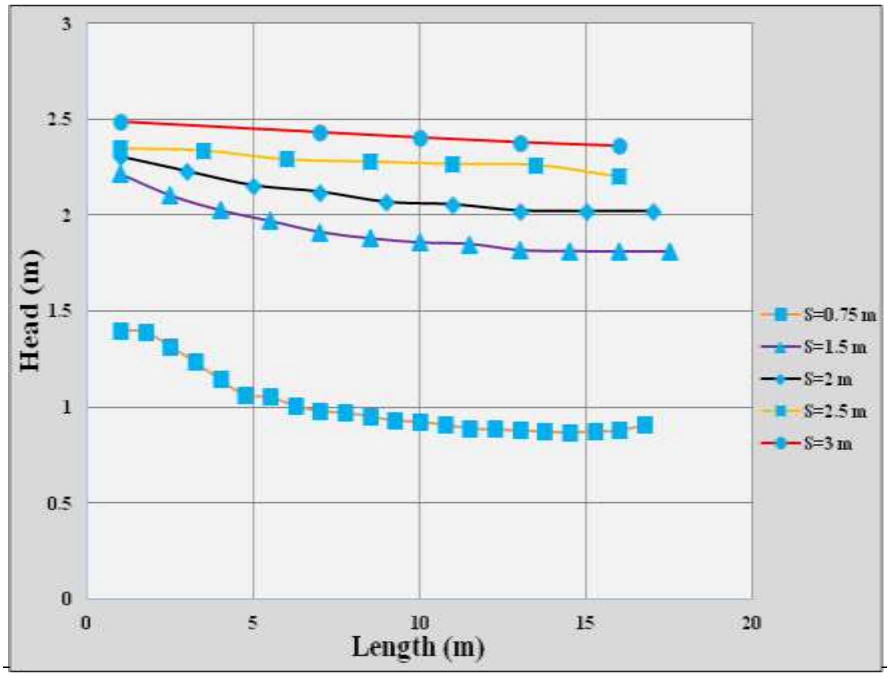

Figure 12. Variation of head/pressure along manifold with different outlets spacing.

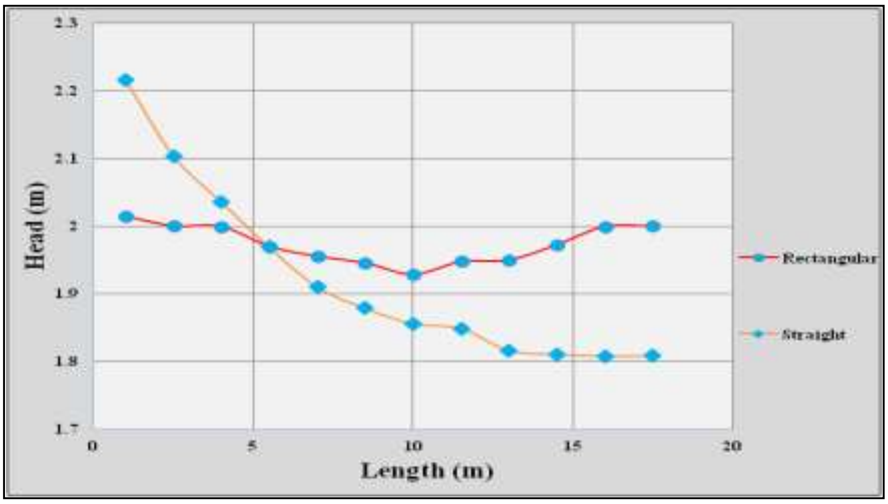

Figure 13. Variation of head/pressure along straight and rectangular manifolds for outlets spacing, S= 1.5 m

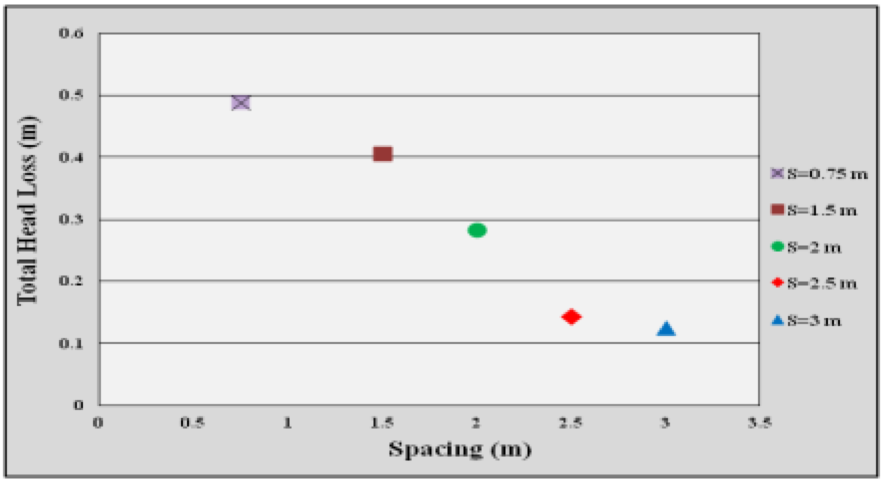

Figure 14. Variation of total head loss along manifold with different outlet spacing.

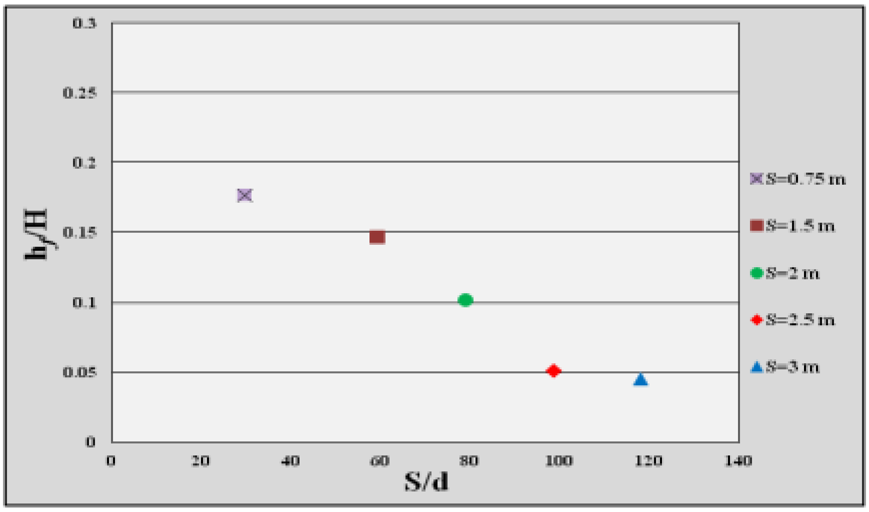

Figure 15. Variation of the normalized head loss with the spacing ratio for a straight manifold.

Many previous studies assumed that the coefficient of friction, *f* along the manifold is constant **(Keller and Bliesner, 1990)**. In fact, this study showed that this assumption is not accurate and variation in the coefficient of friction depends on many pipe characteristics such as diameter, roughness of pipe wall, kinematic viscosity and the flow velocity of the water. The coefficient of friction, *f* is one of the characteristics that affect the friction head losses in manifolds. For calculating the friction head loss in a manifold, Darcy-Weisbach equation was used in the determination of the coefficient of friction. Usually, the friction coefficient is determined by using Moody's diagram. The friction ratio, f_n/f_1 were varied from 0.183 to 33.01. **Fig. 16** shows a comparison of friction ratio, f_n/f_1 for straight and rectangular loop manifolds with constant outlets spacing of 1.5 *m*. Results showed that the friction ratio, f_n/f_1 for the above manifolds was varied from 0.134 to 0.319. The lowest value of the friction ratio was obtained from the calculation of coefficients of friction in various segments of the rectangular loop manifold and it was found to be 0.134 while the greatest value of the friction ratio was obtained from the calculation of coefficients of friction in various segments of the straight manifold and it was found to be 0.319. The value of the coefficient of friction in each manifold segment (f_1, f_2, f_3, f_4, ……, f_n) was affected by Reynolds number of the segment and in another words, it was affected by the discharge flowing in the manifold segment (q_1, q_2, q_3, q_4, ……, q_n). The coefficient of friction in each manifold segment was determined by using Darcy Weisbach equation. The discharge and friction head loss were measured while the length and diameter were known.

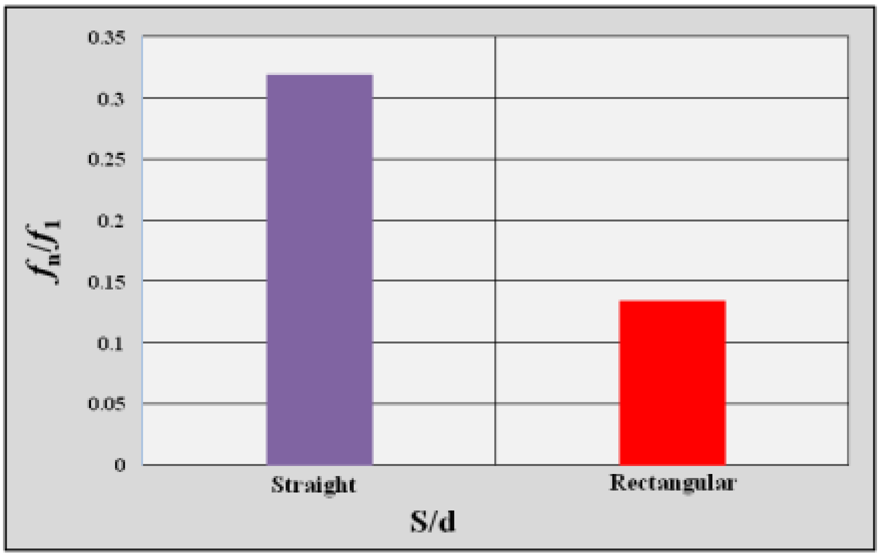

Figure 16. Variation of the friction ratio with manifold configuration for the spacing ratio, S/d=59 for straight and rectangular loop manifolds.

For a constant inlet head, the discharge flowing in a manifold is affected by outlet spacing (small discharge will be associated with greatest outlet spacing and vice versa).

5. CONCLUSION

A physical model was used to simulate the variations in head loss and flow along a manifold. The results of this study show that the flow uniformity and friction loss in a manifold was affected mainly by the outlet spacing and manifold configuration. When the spacing between outlets of straight manifold was 3 m, the calculated uniformity was found to be 84% while the uniformity was increased to 96.5% when the spacing between outlets was increased to 4 folds. For smaller spacing, the number of outlets increased and resulted in greater discharge and greater head loss. The uniformity of the flow in loop rectangular manifold was 95% while that in the straight manifold was 85% and this can be attributed to the gain in head in the loop rectangular manifold.

For manifold outlets with spacing of 3 m, the head loss along the manifold was approximately 26% of that with outlet spacing of 0.75 m. However, the head loss along the straight manifold was 425% greater than that in the loop rectangular manifold. The lowest value of the friction ratio, f1/fn was found in the loop rectangular manifold while greatest friction ratio was found in the straight manifold

NOMENCLATURE

A = are of manifold, m^2.
A_o = area of outlets, m^2 .
d = manifold diameter, m.
H = inlet head, m.
h_f = total head loss along the manifold, m.
L_i = distance of any outlet, m.
L_T = total length of a manifold, m.
Q_T = total discharge from manifold, l/sec.
q1 = discharge at first outlet, l/sec.
q_i = discharge from outlet, l/sec.
qn = discharge at last outlet, l/sec.
S = spacing between outlets, m.
f = coefficient of friction, dimensionless.
f_1 = coefficient of friction in the first manifold segment, dimensionless.
f_n = coefficient of friction in the last manifold segment, dimensionless.
Re = Reynolds number, dimensionless.

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