Effect of Recirculation Ratio on the Uniformity Flow in a High Area Ratio of Outlets Pipe at Different Entrance flow rates

Dr. Wissam H. Alawee
Lecture
Center of truuing-Univ. of tecnology
Wissam_772005@yahoo.com

Dr. Jafar M. Hassan
professor
Mech. Eng. Dep.- Univ.of Technology
Jafarmehdi1951@yahoo.com

Dr. Wahid S. Mohammad
professor
Mech. Eng. Dep.- Univ. of Technology
Wahid_1953@Yahoo.com

ABSRTACT

The uniform flow distrbiution in the multi-outlets pipe highly depends on the several parameters act togather. Therefor, there is no general method to achieve this goal. The goal of this study is to investigate the proposed approach that can provide significant relief of the maldistribution. The method is based on re-circulating portion of flow from the end of the header to reduce pressure at this region . The physical model consists of main manifold with uniform longitudinal section having diameter of 152.4 mm (6 in), five laterals with diameter of 76.2 mm (3 in), and spacing of 300 mm. At first, The experiment is carried out with conventional manifold, which is a closed-end. Then, small amount of water is allowed by controling the valve located at the end of the manifold slowly. The pressure and the flow distribution among the lateral pipes were recorded. Different inlet flows have been tested and the values of these flows are (625, 790, and 950) l/min. The result reveals that the conventional header give high non-uniform flow distrbution and the distribution of flow is greatly improved by using the perposed methods . When the recircluting ratio is of 15%, the non-uniform coefficient (the stander devation) is reduced from 0.48 to 0.13 which means improves in the flow distribution by 75%.

Keyword: Flow distribution**,** manifold**,** uniform

تأثير نسبة إعادة التدوير على توحيد التدفق في انبوب متعدد المنافذ ذو نسبة مساحة عالية عند معدلات تدفق مختلفة

د. وسام حميد عليوي
مدرس
مركز التدريب- الجامعة التكنولوجية

د. جعفر مهدي حسن
استاذ
قسم الهندسة الميكانيكية- الجامعة التكنولوجية

د. وحيد شاتي محمد
أستاذ
قسم الهندسة الميكانيكية- الجامعة التكنولوجية

الخلاصة

التوزيع المنتظم للجريان خلال الانابيب متعددة المنافذ يعتمد بشكل كبير على العديد من المتغيرات التي تؤثر بشكل مجتمع. لذلك لا توجد هناك طريقة محددة لتحقيق هذا الهدف. البحث الحالي هو تطوير لطريقة مقترحة يمكن ان تقلل من سوء توزيع الجريان. تستند هذه الطريقة على سحب نسبة محددة من المائع من النهاية المغلقة للانبوب المتفرع وذلك لتقليل الضغط المرتفع في هذه المنطقة. يتكون مقطع الاختبار المستخدم في البحث من انبوب رئيسي بقطر (152.4 ملم) وخمسة انابيب فرعية بقطر (76.2 ملم)، المسافة بين الانابيب الفرعية كانت (300 ملم). أنجزت التجارب في البداية على مقطع الاختبار بالتصميم التقليدي (النهاية مغلقة) بعد ذلك يتم السماح لكميات مختلفة من الماء من المرور من النهاية المغلقة من خلال صمام تحكم مثبت في نهاية الانبوب. استخدمت ثلاثة قيم مختلفة لكمية التدفق الداخل خلال التجارب وهي (625، 790، 950) لتر/ثانية. بينت النتائج ان عملية سحب

جزء من الماء من النهاية المغلقة للانبوب المتفرع يساهم الى حد كبير في تحسين توزيع الجريان، حيث انه عند نسبة اعادة تدوير مقدارها (15%) قلت قيم معامل الانحراف من 0.48 الى 0.13، وهذا يحسن من توزيع الجريان بمقدار 75%.

1. INTROUDUCTION

Multiple-outlet pipes, often referred to as manifolds, are used in many engineering applications such as infiltration systems, (**Burt et al., 1992**), heat exchanger (**Ranganayakulu et al., 1997**), gas pipe burners (**Mishra et al., 2013**), fuel cells (**Kang et al., 2009**), and ocean outfalls (**Kang et al., 2002**).The flow rate distribution through the lateral pipes depends on the pressure difference across, and, the shape of the header or manifold. Two main challenges of the multiple-outlet pipes are first, to obtain a even flow distribution through lateral pipes, and second, to reduce the pressure loss along the lenght of the manifold (**Hsien and Hin, 2008**, **Tong et al., 2007**). There are two types of multiple-outlet pipes. One of these categories is dividing multiple-outlet pipes, wherein there is a single inlet and multiple exits The other category is combininng multiple-outlet pipes, where there are multiple inlets and a single exit. Combining-flow multiple-outlet pipes are discussed in (**Graber, 2004, 2007**), The present paper addresses dividing-flow multiple-outlet pipes.

A major study has been investigated by (**Acrivos et al., 1959**) for pipe spargers. they found that the flow distribution depends on frictional pressure drop due to the miner and majer losses, and pressure recovery due to the reduction in velocity in the flow direction. In addition, the results showed that the high cross section area of distribution manifold give uniform flow distribution. **Kim et al., 1995**, numerically investigated the effect of outlet header shapes on the flow distribution with the same inlet velocity for three different header geometries (i.e., rectangular, triangular, and trapezoidal) with the Z-type flow direction. Their results indicated that the triangular shape provided the best distribution regardless the inlet flow rate. **Zhe and zhong, 2003**, and **Zhang et al.,2004** conducted the experimental studies as well as CFD simulation studies to understand the effect of manifold configuration in plate heat exchangers. **Tong et al., 2009**, investigated the influence of the cross sectional area of the header. They concluded that the simplest way to obtain outflow uniformity is to enlarge the header to increase the cross sectional area or reduce the flow area ratio.

Hassan et al., 2008, studied numerically the effect of the area ratio (the ratio between sum of areas of all outlets to the area of the main pipe) (AR) on the flow distribution through manifold with five lateral pipes. The simulation results showed that the area ratio has a highly impact on flow distribution through the lateral pipes.

Hassan et al., 2012, performed numerically model to predict the flow distribution in a square cross section header with five branch channels. Three geometrical parameters were considered to investigate their effect on flow distrbution. The geometrical parameters include the distance among laterals, the length of the laterals, and the laterals size. Results showed that increasing the length of the laterals and reducing lateral size give uniform flow profile at lateral outlet.

Fu et al., 1994, studied experimentally and numerically the flow distribution in distribution manifold of square cross-section. **Wang and Yu, 1989**, studied experimentally the flow distribution in inlet and outlet flow for solar collectors. The results show that the header systems can be categorized as pressure regain type and pressure decrease type according to the static pressure distribution along the multiple-outlet pipes. **Kenji and Hidesato, 2005**, presents an experimental study to determine energy loss coefficients for smooth, sharp-edged tees of circular cross-section with large area ratio. By using equations developed from the continuity, energy, and momentum principles they expressed the loss coefficients with correspond correction factors needed in the equations. The comparison of the proposed equations with the experimental results obtained by authors showed that the proposed equations with the correction factors gives good agreement with the experimental results for the area ratio greater than 8.

The literature survey indicates that a flow uniformity are gaining importance in many engineering applications. Also, it was found that impossible achieve this goal for conventional header has area ratio greater than unity (area ratio, AR the ratio between sum of areas of all outlets to the area of the main pipe). **Wissam, 2005**, studied numerically and experimentally several methodologies to improve the flow uniformity in distribution manifold. One of these methodologies were study the effect of drawing ratio (flow out from closed end of manifold) on the flow distribution at the manifold diameter of 101.6 mm (4 in). The results showed that the flow drawing from the end of manifold reduced the flow maldistribution through lateral pipes. The objective of the present study is to investigate the effect of drawing ratio on the flow distribution at **large header diameter** 152.6 mm (6 in), different drawing ratio, and different entrance velocities.

2. EXPERIMENTAL SETUP

The test rig of this study is shown in **Fig. 1**. The rig was built at a selected site in Department of Machinacl Engineering, University of Technology, Baghdad. The test rig, shown in Figure consists of the follwing parts: the main supply pipe, test section, shalow tank to collection water, flow meter, manometer and a centrifugal pump to recycle water to main supply pipe. In order to make a successful and accurate experimental study using the proposed approach, two test sections are made; the first one is made according to conventional design with large area ratio. It is simply shaped with uniform cross section header. The second is made according to the proposed approach. It connected with a globe valve to investigate the effect downstream outflow on uniformity of flow distribution. These test sections consist of a manifold with five-lateral pipe orizontal header and five parallel channels. The header is made of acrylic material to ensure the good visibility of developed flow. It has 1500 mm long and 152.4mm (6 in) diameter.

The inlet of each test section is connected to a 3500 mm length pipe made of clear polyvinyl chloride (PVC) at same diameter of test section. The long pipe provides a fully developed flow. The first test section is dead end where it is closed by a PVC plug. the end of another test section is connected to globel valve. Each branch has 76.2-mm diameter. The branches are regularly 300-mm spaced along the header. The diagrames in **Fig.2**. show the general configuration of the test sections used.

3. FLOW LOOP AND MEASURING DEVICES

The experimental loop is shown in **Fig.3**. Water is the test fluid. The water flow rate from each lateral pipe is collected in a shallow tank, with dimentioin 1500-mm x 1500-mm x 400-mm, then discharged continuously through pipe with diameter of 152.4 mm (6 in) to recycle water by centrifugal pump to main supply tank. The water flow rate is measured by five glass containers with a capacity of 50 liter for each container. The containers are placed on a movable support, which allows it to move freely at the same time of carrying out of experiments. The containers and support are shown in **Fig.4**. Nine pressure tapes are located along the length of the test section. These pressure tapes are used to measure the pressure head in inlet of manifold and at different points along the length of the distribution manifold. The inlet water to the test section is controlled by a globle valve and is measured by a target flo.wmeter.

4. EXPERIMENTAL CONDITIONS

The first tests are carried out with the reference geometry (a multiple-outlet pipes with dead end) to test the effect of the inlet flow rate on the flow distrbution. Inlet flow rates ranges are 625–950 l/min. Three different of drawing ratio are investigated to study its impact on the flow uniformity. All tests are performed at a room temperature and at a atmosphere pressure.

5. MATHEMATICAL MODEL

Fig. 5 shows The control volume in an dividing manifold. The theoretical flow model for present work is based on the same mathematical style as that in the previous work (**Wang, 2008, Wang, 2011).** The mass and momentum balances can be written as follows:

Mass Conservation:

$$\rho AW = \rho A\left(W + \frac{dW}{dZ}\Delta Z\right) + \rho A_L U_L \quad (1)$$

$$U_L = -\frac{AL}{A_l n}\frac{dW}{dZ} \quad (2)$$

where A and A_l are the cross-sectional areas of the header and the lateral pipe, respectively, W_l the axial velocity in header pipe, U_l the velocity in lateral pipe, Z axial coordinate, L length of the header, and *n* number of lateral pipes. Setting $\Delta X = L/n$

.

Momentum Conservation:

$$PA + \rho AW^2 - \tau_W \pi D \Delta Z = \left(P + \frac{dP}{dZ}\Delta Z\right)A + \left(W + \frac{dW}{dZ}\Delta Z\right)^2 + \rho A_l U_l W_l \quad (3)$$

Where P is pressure in the manifold, D diameter of header pipe, τ_w is given by Darcy–Weisbach formula, $\tau_w = f\rho W^2/8$, and $W_l = \beta W$. After inserting τ_w and W_l into Eq. (3) and neglecting the higher orders of ΔX, Eq. (3) can be rearranged as follows:

$$\frac{1}{\rho}\frac{dP}{dZ} + \frac{f}{2D}W^2 + (2-\beta)W\frac{dW}{dZ} = 0 \quad (4)$$

The flow in the lateral pipes can be described by Bernoulli's equation with a consideration of flow turning loss. Hence, the velocity in a lateral pipe, U_l, is correlated to the pressure difference between the manifold and the ambient as follows:

$$P - P_c = \rho\left(1 + C_f + f_l\frac{L_l}{d_l}\right)\frac{U_l^2}{2} = \rho\zeta\frac{U_l^2}{2} \quad (5)$$

where C_f is turning loss coefficient from the manifold into the lateral pipes, H is length of the lateral pipe, d_l is diameter of lateral pipe, f_l is coefficient of the friction for the lateral pipe. Inserting Eq. (2) into Eq. (5), gives:

$$P - P_c = \frac{1}{2}\rho\zeta\left(\frac{AL}{A_l n}\right)^2\left(\frac{dW}{dZ}\right)^2 \tag{6}$$

Eqs. (4) and (6) can be reduced to dimensionless form using the following dimensionless groups.

$$p = \frac{P}{\rho W_o^2}, \qquad p = \frac{P_l}{\rho W_o^2}, \qquad w = \frac{W}{W_o}, \qquad u_l = \frac{U_l}{\rho W_o}, \qquad z = \frac{Z}{L}, \tag{7}$$

$$\frac{dp}{dx} + \frac{fL}{2D}w^2 + (2-\beta)w\frac{dw}{dz} = 0 \tag{8}$$

$$p - p_c = \frac{1}{2}\left(\zeta\frac{A}{A_l n}\right)^2\left(\frac{dw}{dz}\right)^2 \tag{9}$$

where W_0 is the inlet velocity of the manifold. Inserting Eq. (9) into Eq. (8) and after rearranging, one obtains an ordinary differential equation for the velocity in the distributon manifold:

$$\frac{dw}{dz}\frac{d^2w}{dz^2} + \frac{2-\beta}{\zeta}\left(\frac{A_l n}{A}\right)^2 w\frac{dw}{dz} + \frac{fL}{2D\zeta}\left(\frac{A_l n}{A}\right)^2 w^2 = 0 \tag{10}$$

5.1 Analytical Solution

We define two constants**:**

$$Q = \frac{2-\beta}{3\zeta}\left(\frac{A_l n}{A}\right)^2 \tag{11}$$

$$R = \frac{fL}{4D_h\zeta}\left(\frac{A_l n}{A}\right)^2 \tag{12}$$

Thus, Eq. (10) is reduced as follows:

$$\frac{dw}{dz}\frac{d^2w}{dz^2} + 3Qw\frac{dw}{dz} - 2Rw^2 = 0 \tag{13}$$

The general solutions of the governing equation (13) for flow distribution in manifold is similar to that done by **Wang, 2008, 2011**. To solve Equation (13), we assume that the function, $w = e^{rz}$w, is a solution of Equation (13) and substitute it and its derivatives into Eq. (13), we obtain the characteristic equation of Equation (13).

$$r^3 + 3Qr - 2R \tag{14}$$

The solutions of Equation (13) depends on the sign of $Q^3 + R^2$, which have three cases. The solutions of case ($Q^3 + R^2 > 0$) is listed here.

$$r = \left[R + \sqrt{Q^3 + R^2}\right]^{1/3} + \left[R - \sqrt{Q^3 + R^2}\right]^{1/3} \quad ; \quad r_1 = -\frac{1}{2}B + \frac{1}{2}i\sqrt{3}J \quad ; \quad r_2 = -\frac{1}{2}B - \frac{1}{2}i\sqrt{3}J$$

$$Where\, B = \left[R + \sqrt{Q^3 + R^2}\right]^{1/3} + \left[R - \sqrt{Q^3 + R^2}\right]^{1/3}$$

Thus, the general solution of Eq. (13) and boundary conditions can be written as follows:

$$w = e^{-Bz/2}\left[C_1 \cos\left(\sqrt{3Jz/2}\right) + C_2 \sin\left(\sqrt{3Jz/2}\right)\right] \qquad (15)$$

$$w = 0, \quad at \quad z = 1$$
$$\mathrm{w} = 1, \quad \mathrm{at} \quad \mathrm{z} = 0$$

The equation of axial velocity in the manifold can be written as follows:

$$w = e^{-Bz/2}\left[\frac{\sin\left(\sqrt{3J(1-z)/2}\right)}{\sin\left(\sqrt{3J/2}\right)}\right] \qquad (16)$$

The equation of velocity of lateral can be written as follows:

$$u_l = \left(\frac{A}{2nA_l}\right) e^{-Bz/2}\left[\frac{B\sin(\sqrt{3J}(1-z)/2) + \sqrt{3J}\cos(\sqrt{3J}(1-z)/2)}{\sin(\sqrt{3J}/2)}\right] \qquad (17)$$

Flow distribution through lateral pipe:

$$v_{\mathrm{i}} = \left(\frac{\mathrm{nA_l}}{\mathrm{A}}\right)\mathrm{u_l} = \frac{1}{2}e^{-Bz/2}\left[\frac{B\sin(\sqrt{3J}(1-z)/2) + \sqrt{3J}\cos(\sqrt{3J}(1-z)/2)}{\sin(\sqrt{3J}/2)}\right] \qquad (18)$$

5. RESULTS AND DISCUSSION

According to **Hassan et al., 2008** and **Wissam, 2015** the flow distribution along multi-outlet pipe is depended largely on the area ratio. They found that, when the area ratio increases to larger than unity, the flow distribution along multi-outlet pipe is far from uinform. On the contrary, when the area ratio decreases, the distribution of flow improves dramatically. Therefore, the present results are expected for area ratio greater than unity. These results will be a reference to investigate the effect of proposed approach on the flow and pressure distribution.

The results of the flow rate for each outlet at three different inlet flow rates (625, 790, 950) l/min. are given in **Fig.6**. As expected, the water flow in the outlets tends to increase, starting with the first outlet which is badly fed to the last one which is so highly fed (more than twice the mean water flow rate). In contrast, the pressure distribution along the length of manifold also be uneven.

There is a clear flow maldistribution which can be explained as follows: there are two factors control the pressure variations in multi-outlet header: friction and momentum. These two factors work in opposite directions to each other. The friction effect lowers the pressure along the header in opposing the momentum effect. In tradetional header, the momentum cannot balance the friction effect, resulting in a non-uniform flow distribution. When the multi-outlet pipe is dead end, water is recirculating at the closed end. This causes unstable flow and pressure increase, resulting in an increase in flow rate through branch No.5. This is in agreement with the findings in reference, **Pertorius, 1997**.This is in agreement with the results of reference, **Pertorius, 1997**.

The behavior of flow distribution is consistent with the pressure distributions that have been displayed in **Fig.7**. This figure shows that the pressure increases with increasing of downstream distances. Since the pressure difference drives the per-outlet water flow rate, so it is necessary to increase the flow rate with downstream distance.

The difficulty in obtaining uniform distribution is due to pressure build-up at the header end. To reduce the pressure, a portion of the flow is re-circulated to supply tank were carried out. **Figs. 8, 9**, and **10** present the results of flow rate at drawing ratios of 5%, 10%, and 15% respectively. From these figures, it can be seen that the ratio of withdrawal water from the closed end of manifold helps to a great extent to improve the distribution of the flow regardless of inlet flow rate (in the range used in the experiment that is from 625 l/min. to 950 l/min.). When the drawing ratio is 0%, it means that there is no flow from the end of the manifold. In this case, a part of the kinetic energy is converted to a rise in pressure at that region.Thus, the water flow through the outlets is increasing towards dead end of the header. When the drawing ratio is certain percentage, the pressure at the dead end will decrease and hence the water flow from the last outlet is also decreases. When the drawing ratio increses from 5% to 15%, the pressure along the manifold was become nearly uniform which gives a better flow distribution through the outlets.

Fig.11 shows the percentage of flow rate fraction for each outlet takes from the total flow at different drawing ratio. Comparing these results with those of traditional header (closed end), a clear improvement can be seen in flow distribution. For example, when the traditional header is used, the discharge from last outlet is about 29.5% of the total flow rate while for the header with 15% drawing ratio, the percentage is reduced from 29.5% to 22.5%. In other words, the flow discharge from first outlet is 64% less than that from last outlet but when the header with 15% drawing ratio is used, this percentage is reduced from 64% to 20%.

The percentage of absolute mean deviation from average flow rate is shown in **Fig.12**. From this figure, the values of standard deviation (STD) are 0.48, 0.439, 0.311, and 0.241 at Drawing ratio of 0%, 5%, 10%, and 15%, respectively. The lowest value of (Φ) was of the header with 15% drawing ratio that corresponding to 0.025. It is clear that water withdrawal in certain proportions from the high pressure region (in which the kinetic energy is converted to a rise in pressure) would help reduce pressure in this region, thus resulting in improved flow distribution.

A comparison between the present results and the result of **Wissam, 2015** shows (see Table 1) that the selection of drawing ratio depends largely on the header diameter. On the other hand, the total inlet flow rate does not affect the flow distribution. When the drawing ratio of 10%, the value of stander deviation is (0.377). Also, when using the same ratio but with header diameter of (6 in), the value of deviation coefficient is reduces from 0.377 to 0.311.

Experimental tests for flow distribution from manifold have been conducted, which made it possible to validate the analytical procedures. **Fig. 13** shows comparison between the computed and experimental flow rate per-outlet. It can be clearly seen from the figures that the different of flow rate between computed and experimental value is acceptable.

5. CONCLUSION

Two test sections representing different header structures were used in this study. The first test section is uniform header, the second header with drawingratio. In both test sections, the diameter of the main pipe was 152.4 mm and of the lateral pipe 76.2 mm. the method of withdrawal water from the dead end of manifold is a very successful approach to improve flow uniformity. where, the flow distribution is improved by 75% which means the stander devation is reduced from 0.48 to 0.241.Three different values of inlet flow rate of (625, 790,950) l/min had been used in the experiments. From the results, it is found that change in the total flow rate has a slight effect on flow uniformity. Therefore, it can be safely said that the inlet flow rate has no effect on flow distribution.

ACKNOWLEDGEMENTS

The authors would like to thank the Mechanical Engineering depertment, University of technology for its assistance.

REFFERENCE

- Acrivos, A., Babcock, B.D., and Pigford, R.L., 1959. Flow distribution in manifolds. Chem. Eng. Sci. vol. 10, pp. 112–124.
- Alawee, W. H., 2015, Solution Methodologies for the Fluid Flow Distribution Manifold Problem, Ph.D Thesis, Department of Mechanical Engineering, University of Technology, Iraq.
- Burt, C. M., Walker, R. E., Styles, S. W., 1992, Infiltration System Evaluation Manual. Irrigation Training And Research Center,. California polytechnic state, Univcity San Luis Obispo, CA.
- Bleninger, T., Lipari, G., and Jirka, G., 2002, Design And Optimization Program For Internal Diffuser, 2nd Int. Conf. on Marine Waste Water Discharges, MWWD 2002.
- FU H., Watkins, A. P., and Yianneskis M., 1994, The Effects Of Flow Split Ratio And Flow Rate In Manifolds,. Int. J. Numerical Methods in Fluids, vol.18, no.9, pp. 871-886.

- Graber, S. D., 2004, Concepts of spatially varied flow.” Proc., HTFED, 2004 ASME Heat Transfer/Fluids Engineering Summer Conf., ASME, New York.
- Graber, S. D., 2007, Full-flowing collection conduits with nonuniform inflow.” Journal. Environment Engineering, vol. 133, no. 6, pp. 575–580.
- Hassan, J. M., Mohamed, T. A., Mohammad, W. S., and Alawee,W. H., 2014, Experimental and Numerical Study on the Improvement of Uniformity Flow for Three-Lateral Dividing Manifold, World Research & Innovation Convention on Engineering & Technology, Putrajaya, Malaysia, 25-26 November 2014.
- Hsien-Ter Chou and Hin-Chi Lei, 2008, Outflow Uniformity along a Continuous Manifold, Journal of Hydraulic Engineering,ASCE / SEPTEMBER 2008 , pp. 1383-1388.
- Hassan, J. M.,208, Flow Distribution in Manifolds, Journal of Engineering and Development, vol. 12, no.4, pp. 159-177.
- Hassan, J. M., 2012, Study of Three Dimensional Fluid Flow in Manifold-Laterals System, Eng. & Tech. Journal, vol.30, no. 7,pp. 1132-1148.
- Kang, S., Min, K., Mueller, F., and Brouwer, J., 2009, Configuration effects of air, fuel, and coolant inlets on the performance of a proton exchange membrane fuel cell for automotive applications, International Journal of Hydrogen Energy, vol.34, no.16, pp. 6749–6764.
- Kim, S., Choi, E., and Cho, Y.I., 1995, The effect of header shapes on the flow distribution in a manifold for electronic packaging applications, International Communicationsin Heat and Mass Transfer, vol. 22, pp. 329-341.
- Kenji, O., Hidesato, I., 2005, Energy Losses at Tees with Large Area Ratios, Transactions of the ASME, Journal of Fluids Engineering, Vol. 127, pp. 110-116.
- Mishra, N. K., Muthukumar, P., and Mishra, S. C., 2013, Performance Tests on Medium-Scale Porous Radiant Burners for LPG Cooking Applications, International Journal of Emerging Technology and Advanced Engineering Vol. 3, Special Issue 3, pp. 126-130.
- Pertorius W.A., Dividing- flow Manifold Calculations with a Spreadsheet, water science, 23 (2) (1997) 147-150.
- Ranganayakulu, Ch., Seetharamu, K. N., and Sreevatsan, K.V., 1997, The Effects of Inlet Fluid FlowNonuniformity on Thermal Performance and Pressure Drops in Crossflow Plate-fin Compact Heat Exchangers, Int. J. Heat Mass Transfer, vol. 40, no. 1, pp. 27–38.
- Tong, J.C.K., Sparrow, E.M., Abraham, J.P., 2007, Attainment of flowrate uniformity in the channels that link a distribution manifold to a collection manifold, Journal Fluids Engineering, vol. 129, pp.1186–1192.
- Tong, J.C., Sparrow, E.M., and Abraham, J.P.,2009, Geometric strategies for attainment of identical outflows through all of the exit ports of a distribution manifold in a manifold system, Appl. Therm. Eng., vol. 29, pp. 3552–3560.
- Zhe Z., Yan-zhong, L., 2003, CFD simulation on inlet configuration of plate-fin heat exchangers, Cryogenics, vol. 43, no. 12, pp. 673-678.

- Zhe, Z., Yan-zhong, L., and Qing, X., 2004, Experimental research on the effects of distributor configuration in plate-fin heat exchangers, Heat Transfer-Asian Research, vol. 33, no.6, pp. 402.
- Wang, X. A. and P. Yu, Isothermal flow distribution in header systems, International Journal of Solar Energy, 7(1989)159-169
- Wang J., Pressure drop and flow distribution in parallel-channel configurations of fuel cells: U-type arrangement, International journal of hydrogen energy, 33(2008) 6339 – 6350.
- Wang, J., Theory of flow distribution in manifolds, Chem. Eng. J., 168 (2011)1331–1345.

7. NOMENCLATURE

C_f = coefficients of turning losses.
D= diameter of manifold, m.
d_l = diameter of the lateral pipe, m.
f =friction factor
A, A_l = cross-sectional area of manifold and lateral pipe, m^2.
H= length of lateral pipe, m.
L= length of manifold, m.
n = numbers of lateral pipes.
Pa = ambient pressure
p_a = dimensionless ambient pressure
P = pressure in manifold
P = dimensionless pressure.
Q = coefficient in Eq. (13), defined by Eq. (11)
R = coefficient in Eq. (13), defined by Eq. (11)
r, r_1, r_2 = roots of characteristic equation.
W = velocity in manifold (m/s)
w =dimensionless velocity in manifold.
U_l = velocity of lateral pipe, m/s.
u_l = dimensionless velocity of lateral pipe.
vc =dimensionless volume flow rate in lateral pipes.
β = average velocity ratio in manifold (W_l/W)
ρ = fluid density (kg/m_3)
τ_w = wall shear stress (N/m_2)
ζ = average total head loss coefficient for port flow

Table 1. A comparison of the results obtained in the present study with those of Ref., Alawee,2015.

Researcher	Drawing ratio, %	Percentage of flow rate fraction for each outlet takes from the total flow					
		Outlet 1	**Outlet 2**	**Outlet 3**	**Outlet 4**	**Outlet 5**	**STD**
Wissam, 2015 **Header diameter=101.6 mm (4")**	8	11%	15%	12%	22%	22%	**0.371**
	10	11.9	16.6	23.1	23.6	24.8	**0.354**
The present work **Header daimeter=152.6 mm (6")**	10	13.3	16.6	22.0	23.8	24.1	**0.311**
	15	14.6	18.5	21.0	21.4	21.9	**0.241**

Figure 1. Plate of the experimental rig for five-lateral manifold.

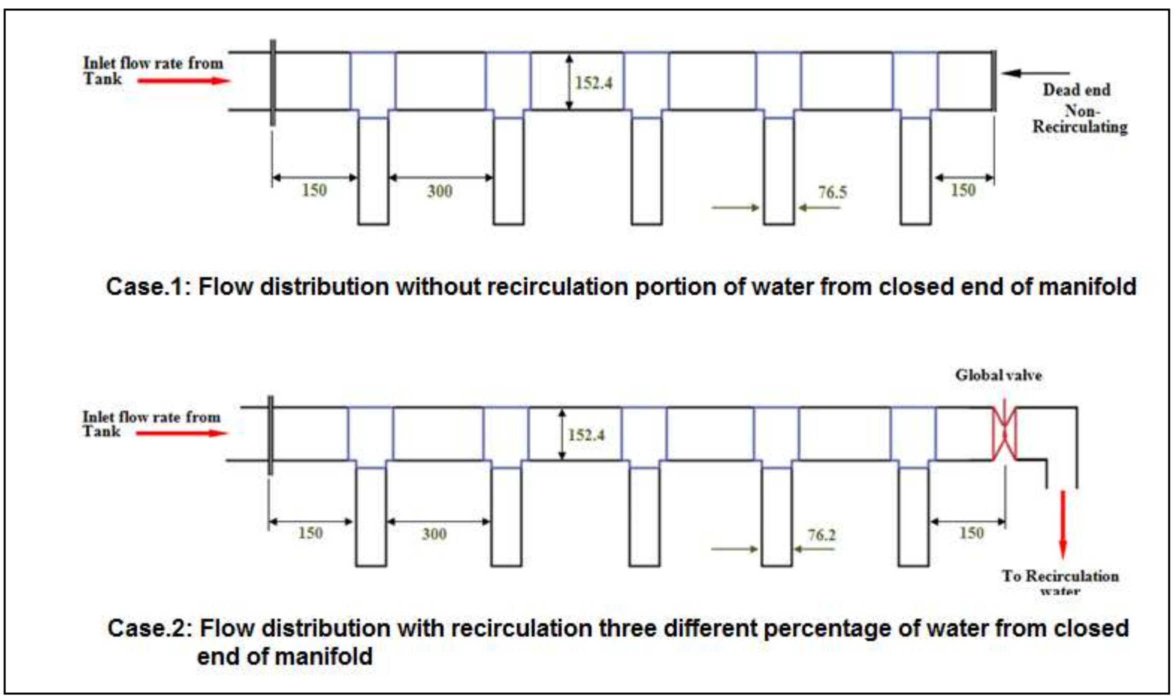

Figure 2. Multi-outlets pipe with/without recirculation ratio .

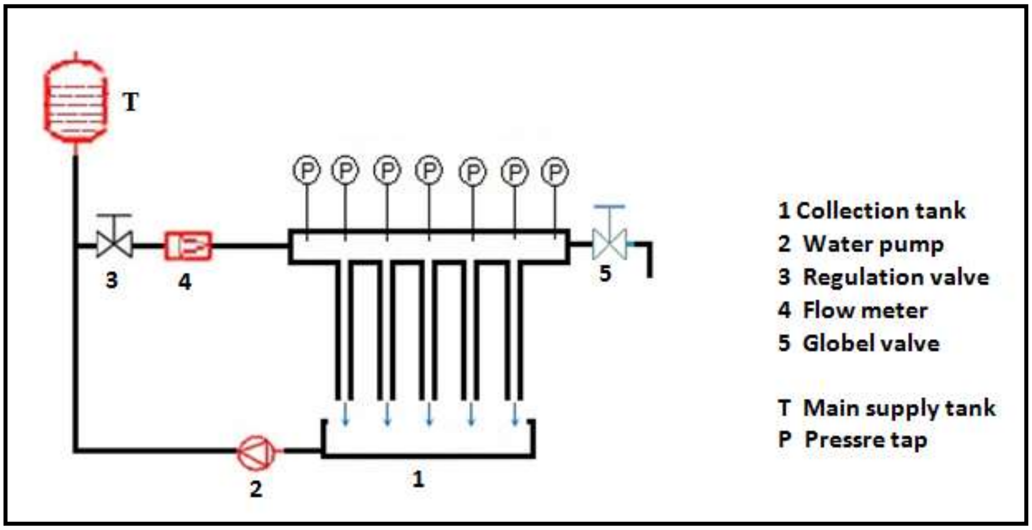

Figure 3: Schematic diagram of flow loop.

Figure 4: Containers to measure water from outlets

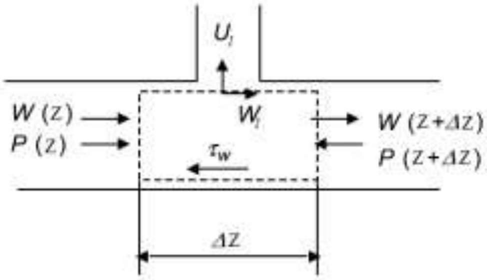

Figure 5: Control volume for the distrbution manifold.

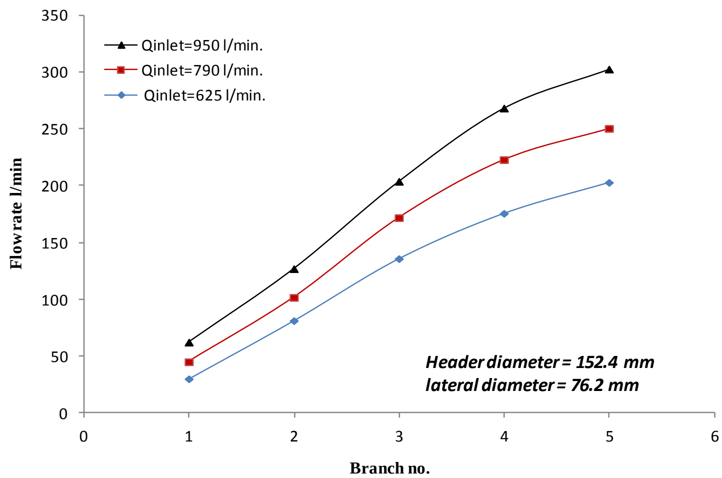

Figure 6: Flow distribution plot at three value of inlet flow water .

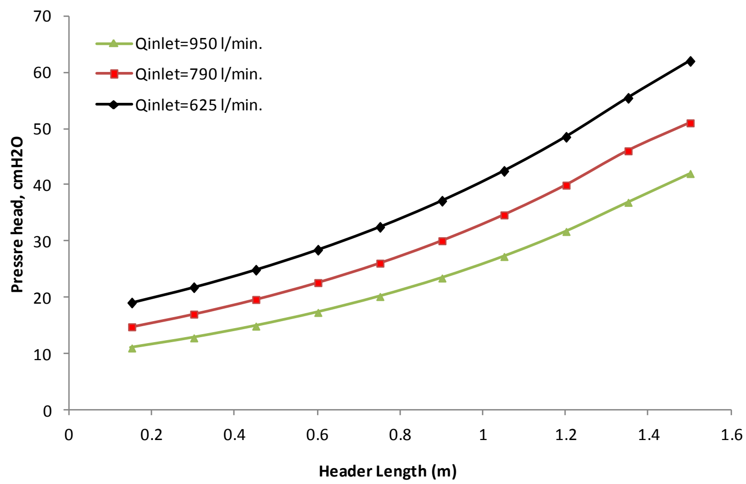

Figure 7: Variations of pressure head along the manifold .

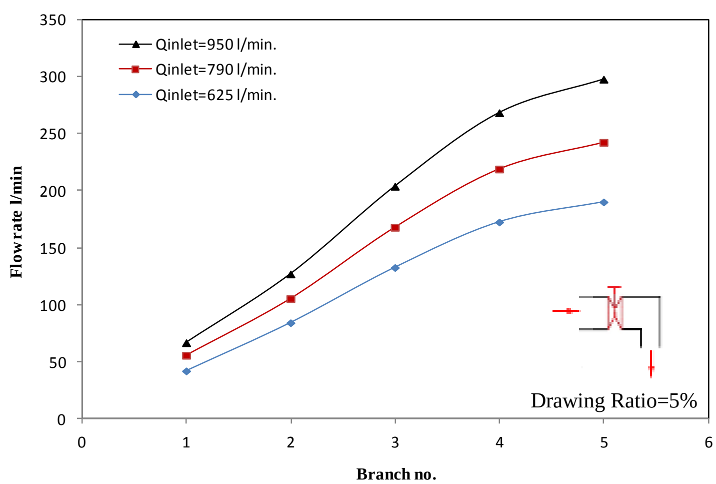

Figure 8: Flow distribution plot of manifold with 5% drawing ratio at three value of inlet flow water .

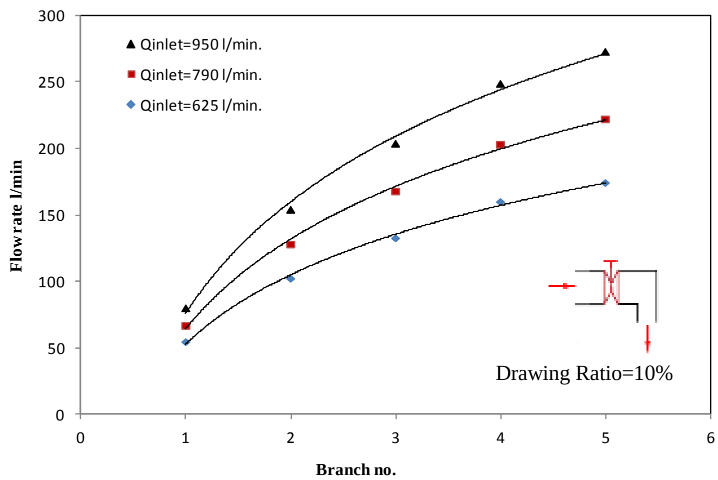

Figure 9: Flow distribution plot of manifold with 10% drawing ratio at three value of inlet flow water .

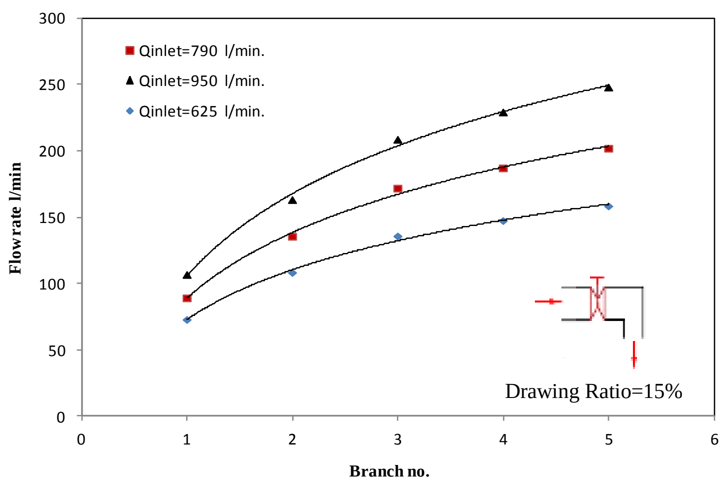

Figure 10: Flow distribution plot of manifold with 15% drawing ratio at three value of inlet flow water.

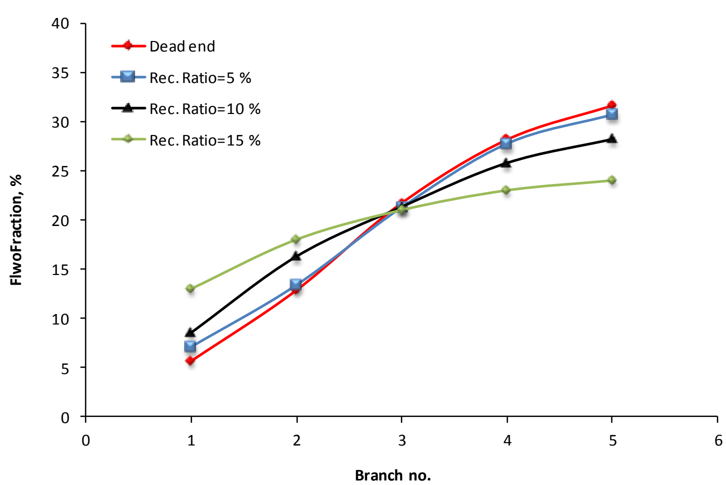

Figure 11: Flow rate fraction at three value of drawing ratio.

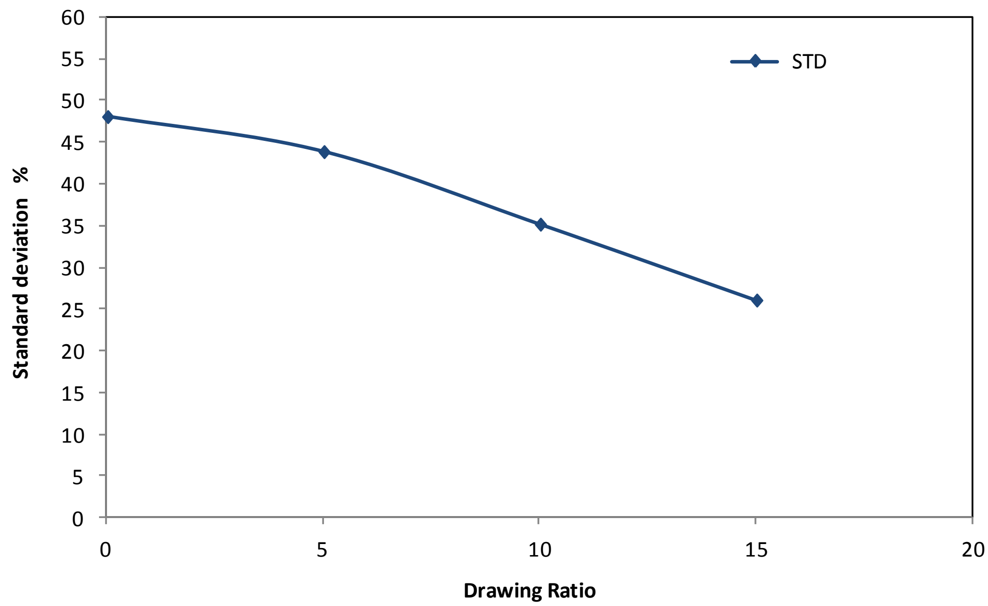

Figure 12: Percentage of absolute mean deviation from average for three drawing ratio

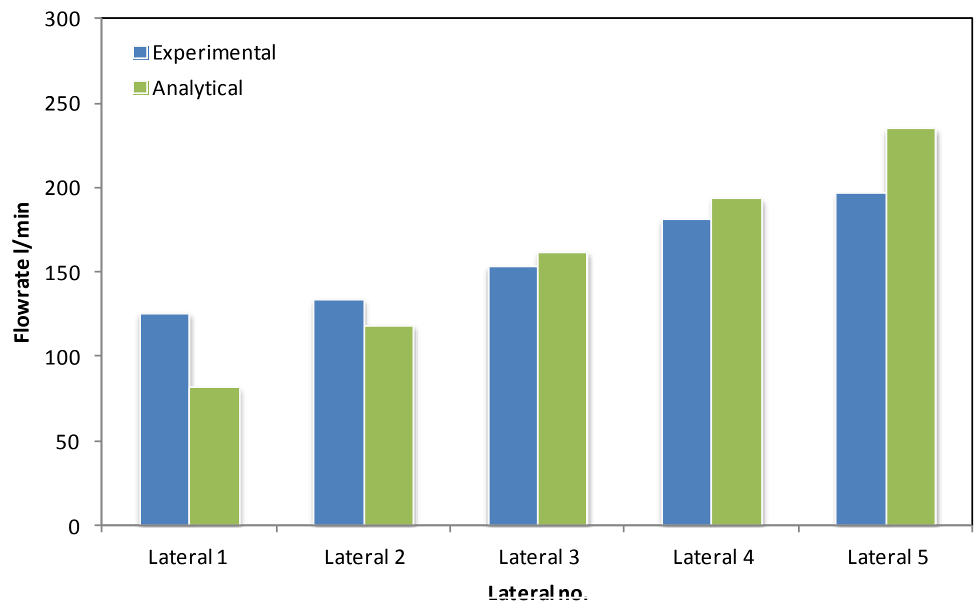

Figure 13: flow distribution per lateral pipe for manifold