



**UNIVERSITI PUTRA MALAYSIA**

***MINOR LOSSES FROM A PIPE WITH DIFFERENT DIAMETERS AND  
MULTIPLE OUTLETS***

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**MINOR LOSSES FROM A PIPE WITH DIFFERENT DIAMETERS AND  
MULTIPLE OUTLETS**

**By**

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## **DEDICATION**

**I warmly dedicate this report to my Supervisor, Dr. Mohd. Shahrizal bin Ab Razak,  
For always have confidence on me to complete this project.**

**My beloved parents and family,  
Abdul Karim bin Shariff and Zanab binti Said,  
Whom I love the most,  
Always give support for me through my ups and downs,  
My best friend, Nur 'Izzaty binti 'Iz,  
Your support and courage is my strength,  
Friends and everyone, whom are the best,  
Success of mine is successes of all of you.**

## **ABSTRACT**

A pipe that permits water passage with multiple outlets distributed along the pipe centerline and consists of dead end is known as manifold. Manifolds are used to distribute and also to collect fluids for various engineering applications especially in water supply. While the water is transported along the manifold, there will be losses occurred, that is known as head loss which is divided into major and minor loss. Major loss is due to friction loss while minor loss is due to various piping components along the pipe. In this study, a physical model to demonstrate the manifold was designed, fabricated and installed in order to assess the variations of minor losses and discharge of each outlet along the manifold. The manifold was made of Poly Vinyl Chloride (PVC) since it has common use in the water supply systems. From data analysis, it is found that the outlet spacing and area ratio are factors that affect the minor loss for multiple outlets pipe. There is a relationship between minor loss, pipe diameter and various fittings throughout the manifold. The pressure along manifold with outlets is decreased thus produces maximum minor loss at the last outlet before the dead end manifold. For a pipe without outlet, the pressure along manifold increases towards the dead end due to Bernoulli's effect and there is no energy loss due to constant water pressure before and after each outlet. A larger area ratio pipe has better uniformity in a multiple outlets pipe with uniformity coefficient approximately equals to 1.0. The water temperature recorded is useful to determine the kinematic viscosity as to calculate the Reynolds number,  $Re$ . The flow needs to be in complete turbulence condition as to validate the formula used to calculate the theoretical  $k$  and compared with the experimental  $k$ .

## ABSTRAK

Paip yang membenarkan laluan air dengan beberapa cabang sepanjang paip dan tertutup di akhirnya dikenali sebagai pancarongga. Pancarongga boleh digunakan untuk mengedar dan juga untuk mengumpul cecair untuk pelbagai aplikasi kejuruteraan terutamanya dalam bekalan air. Semasa air sedang diangkut bersama-sama pancarongga, akan ada kehilangan berlaku yang dikenali sebagai kehilangan turus yang terbahagi kepada kehilangan besar dan kecil. Kehilangan besar adalah disebabkan oleh kehilangan geseran manakala kehilangan kecil adalah disebabkan oleh pelbagai komponen paip sepanjang paip. Dalam kajian ini, model fizikal untuk menunjukkan fungsi pancarongga direka, dibina dan dipasang untuk menilai variasi kehilangan kecil dan kadar air sepanjang keluaran paip ini. Pancarongga diperbuat daripada *Poly Vinyl Chloride (PVC)* kerana ia biasa digunakan dalam sistem bekalan air. Daripada analisis data, didapati bahawa jarak keluaran dan nisbah keluasan paip adalah faktor-faktor yang memberi kesan kepada kehilangan kecil di dalam pancarongga. Terdapat hubungan antara kehilangan kecil, diameter paip dan pelbagai kelengkapan di pancarongga. Tekanan di sepanjang pancarongga pelbagai keluaran semakin berkurangan justeru itu menghasilkan nilai maksima kehilangan kecil pada keluaran terakhir sebelum pancarongga terakhir. Bagi paip tanpa keluaran, tekanan di sepanjang pancarongga semakin meningkat ke arah akhir paip disebabkan oleh kesan Bernoulli dan tiada kehilangan tenaga disebabkan oleh tekanan air yang berterusan sebelum dan selepas setiap keluaran. Lebih besar nisbah keluasan paip mempunyai keseragaman yang lebih baik dalam beberapa cawangan paip dengan pekali keseragaman adalah lebih kurang

sama dengan satu. Suhu air yang dicatatkan adalah berguna untuk menentukan kelikatan kinematik untuk mengira nombor Reynold,  $Re$ . Aliran perlu berada dalam keadaan pergolakan lengkap untuk mengesahkan formula yang digunakan untuk mengira  $k$  teori dan dibandingkan dengan  $k$  eksperimen.



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## TABLE OF CONTENT

|   | <b>PAGE</b> |
|---|-------------|
| <b>DEDICATION</b>                             | <b>ii</b>   |
| <b>ABSTRACT</b>                               | <b>iii</b>  |
| <b>ABSTRAK</b>                                | <b>iv</b>   |
| <b>ACKNOWLEDGEMENT</b>                        | <b>vi</b>   |
| <b>APPROVAL</b>                               | <b>vii</b>  |
| <b>DECLARATION</b>                            | <b>viii</b> |
| <b>LIST OF TABLES</b>                         | <b>xii</b>  |
| <b>LIST OF FIGURES</b>                        | <b>xii</b>  |
| <b>CHAPTER</b>                                |             |
| <b>1 INTRODUCTION</b>                         |             |
| <b>1.0 BACKGROUND</b>                         | <b>1</b>    |
| <b>1.1 PROBLEM STATEMENT</b>                  | <b>4</b>    |
| <b>1.2 OBJECTIVES</b>                         | <b>5</b>    |
| <b>1.3 SCOPE AND LIMITATIONS OF THE STUDY</b> | <b>6</b>    |
| <b>1.4 THESIS OUTLINE</b>                     | <b>7</b>    |
| <b>2 LITERATURE REVIEW</b>                    |             |
| <b>2.0 BACKGROUND</b>                         | <b>9</b>    |
| <b>2.1 LOSSES IN MANIFOLD</b>                 | <b>9</b>    |
| <b>2.1.1 Major Loss</b>                       | <b>12</b>   |

|          |  |           |
|----------|--|-----------|
|          | <b>2.1.2 Minor Loss</b>  | <b>15</b> |
|          | <b>2.2 UNIFORMITY OF MANIFOLD</b>  | <b>18</b> |
|          | <b>2.3 RESISTANCE COEFFICIENT</b>  | <b>20</b> |
|          | <b>2.3.1 Sudden Contraction</b>  | <b>21</b> |
|          | <b>2.3.2 Gradual Contraction</b>   | <b>22</b> |
|          | <b>2.3.3 Valves and Fittings</b>   | <b>24</b> |
|          | <b>2.4 SUMMARY OF LITERATURE REVIEW</b>  | <b>27</b> |
| <b>3</b> | <b>METHODOLOGY</b>   |           |
|          | <b>3.0 BACKGROUND</b>  | <b>29</b> |
|          | <b>3.1 MODEL DESIGN AND FABRICATION</b>  | <b>31</b> |
|          | <b>3.1.1 Multiple Outlet Pipe (Manifold) Design</b>  | <b>32</b> |
|          | <b>3.1.2 Multiple Outlet Pipe (Manifold) Fabrication Process</b>   | <b>35</b> |
|          | <b>3.1.3 Water Tank</b>  | <b>37</b> |
|          | <b>3.1.4 Measuring Device</b>  | <b>39</b> |
|          | <b>3.2 EXPERIMENTAL DESIGN</b>   | <b>40</b> |
|          | <b>3.3 EXPERIMENTAL PROCEDURE</b>  | <b>40</b> |
| <b>4</b> | <b>RESULTS AND DISCUSSIONS</b>   |           |
|          | <b>4.0 BACKGROUND</b>  | <b>42</b> |
|          | <b>4.1 VARIATION OF PRESSURE HEAD AND MINOR LOSS ALONG PVC PIPE WITH DIFFERENT OUTLET SPACING AND AREA RATIO</b> | <b>43</b> |

|       |   |    |
|-------|---|----|
| 4.1.1 | Variation of Pressure Head and Minor Loss at Different Outlet Spacing   | 44 |
| 4.1.2 | Variation of Minor Loss with Different Area Ratio Pipe  | 47 |
| 4.2   | VARIATION OF UNIFORMITY COEFFICIENT ALONG PVC PIPE WITH DIFFERENT OUTLET SPACING AND AREA RATIO   | 48 |
| 4.3   | VARIATION OF PRESSURE HEAD IN A MANIFOLD HAVING SAME LENGTH, DIAMETER AND DISCHARGE WITH AND WITHOUT OUTLETS                                | 50 |
| 4.4   | VARIATION OF RESISTANCE COEFFICIENT, K OF A MULTIPLE OUTLETS PIPE WITH VARIOUS SPACING AND AREA RATIO AND COMPARED WITH THEORETICAL K VALUE | 53 |
| 5     | CONCLUSIONS AND RECOMMENDATIONS   |    |
| 5.1   | CONCLUSIONS   | 57 |
| 5.2   | RECOMMENDATIONS   | 59 |
|       | REFERENCES  | 60 |
|       | APPENDICES  | 62 |
|       | APPENDIX A – RAW DATA OBTAINED FROM EXPERIMENT  | 63 |
|       | APPENDIX B – CALCULATED RESULTS   | 67 |
|       | APPENDIX C – SAMPLE CALCULATION   | 71 |

## LIST OF TABLES

| TABLE     |  | PAGE |
|-----------|--|------|
| Table 2.1 | Resistance Coefficient – Sudden Contraction  | 22   |
| Table 2.2 | Resistance in Valves and Fittings Expressed as Equivalent Length in Pipe Diameter, $L_e/D$ | 25   |
| Table 2.3 | Friction Factor in Zone of Complete Turbulence for New, Clean Commercial Steel Pipe        | 26   |
| Table 3.1 | Experimental Details   | 40   |
| Table 4.1 | Area Ratio Based on Different Pipe Diameter Combination                                    | 43   |
| Table 4.2 | Pressure Head and Minor Loss Data  | 44   |
| Table 4.3 | Discharge and Uniformity Coefficient Data  | 49   |
| Table 4.4 | Pressure Head in a Manifold with and without Outlets                                       | 51   |
| Table 4.5 | Reynolds Number Data   | 54   |
| Table 4.6 | Resistance Coefficient, $k$ from Experimental and Theoretical                              | 56   |

## LIST OF FIGURES

| FIGURES    |  | PAGE |
|------------|--|------|
| Figure 2.1 | Bernoulli's Principle Theory Explanation     | 11   |
| Figure 2.2 | Flow through a Bend Pipe                     | 17   |
| Figure 2.3 | Sudden Contraction Geometry                  | 21   |
| Figure 2.4 | Gradual Contraction Geometry                 | 22   |
| Figure 2.5 | Resistance Coefficient – Gradual Contraction | 23   |
| Figure 2.6 | Resistance Coefficient – Gradual Contraction | 24   |

|                   |   |           |
|-------------------|---|-----------|
| <b>Figure 2.7</b> | <b>Moody's Diagram</b>  | <b>26</b> |
| <b>Figure 3.1</b> | <b>Plan View of the Manifold</b>  | <b>33</b> |
| <b>Figure 3.2</b> | <b>Elevation View of the Manifold</b>   | <b>34</b> |
| <b>Figure 3.3</b> | <b>Manifold Fabrication Process</b>   | <b>36</b> |
| <b>Figure 3.4</b> | <b>Leakage in Pipe</b>  | <b>37</b> |
| <b>Figure 3.5</b> | <b>Repairing of the Leakage Pipe</b>  | <b>37</b> |
| <b>Figure 3.6</b> | <b>Completed Manifold</b>   | <b>37</b> |
| <b>Figure 3.7</b> | <b>Existing Water Tank</b>  | <b>38</b> |
| <b>Figure 3.8</b> | <b>Manometer Setup</b>  | <b>39</b> |
| <b>Figure 4.1</b> | <b>Variation of Pressure Head and Minor Loss with Same Area Ratio at Different Outlet Spacing (AR=0.50)</b> | <b>45</b> |
| <b>Figure 4.2</b> | <b>Variation of Pressure Head and Minor Loss with Same Area Ratio at Different Outlet Spacing (AR=0.33)</b> | <b>46</b> |
| <b>Figure 4.3</b> | <b>Variation of Pressure Head and Minor Loss with Same Area Ratio at Different Outlet Spacing (AR=0.25)</b> | <b>46</b> |
| <b>Figure 4.4</b> | <b>Variation of Pressure Head and Minor Loss with Same Area Ratio at Different Outlet Spacing (AR=0.17)</b> | <b>47</b> |
| <b>Figure 4.5</b> | <b>Variation of Minor Loss in Different Area Ratio at Various Outlet Spacing</b>                            | <b>48</b> |
| <b>Figure 4.6</b> | <b>Variation of Uniformity Coefficient in Different Area Ratio Pipe</b>                                     | <b>49</b> |
| <b>Figure 4.7</b> | <b>Comparison of Pressure Head in the Same Pipe with and without Outlet (AR = 0.50)</b>                     | <b>51</b> |
| <b>Figure 4.8</b> | <b>Comparison of Pressure Head in the Same Pipe with and without Outlet (AR = 0.33)</b>                     | <b>52</b> |
| <b>Figure 4.9</b> | <b>Comparison of Pressure Head in the Same Pipe with and without Outlet (AR = 0.25)</b>                     | <b>52</b> |

|                    |  |           |
|--------------------|--|-----------|
| <b>Figure 4.10</b> | <b>Comparison of Pressure Head in the Same Pipe with and without Outlet (AR = 0.17)</b>                                  | <b>53</b> |
| <b>Figure 4.11</b> | <b>Variation of Reynolds Number in Different Area Ratio Manifold</b>   | <b>55</b> |
| <b>Figure 4.12</b> | <b>Comparison of Resistance Coefficient <math>k_{\text{experimental}}</math> and <math>k_{\text{theoretical}}</math></b> | <b>56</b> |



# **CHAPTER ONE**

## **INTRODUCTION**

### **1.0 BACKGROUND**

A natural or artificial channel which conveyed fluid with circular cross section is called pipe while other than circular shape is called as a duct. The channel that permit water passage and have dead end with branches or multiple outlets distributed along the channel centerline also known as manifold. Manifold is usually used to distribute and collect fluids. Manifolds have applications in various daily life engineering fields such as civil engineering, irrigation engineering, chemical engineering and mechanical engineering. There are many types of manifold in engineering that include exhaust manifold which is an engine part that collects the exhaust gases from multiple cylinders into one pipe, hydraulic manifold which a component used to regulate fluid flow in a hydraulic system thus controlling the transfer of power between actuators and pumps, inlet manifold which an engine part that supplies the air or fuel mixture to the cylinders and vacuum gas manifold which is an apparatus used in chemistry to manipulate gases. Applications of manifold in civil engineering can be found in water supply system, sewage disposal, water and wastewater treatment plant processes, navigation locks and hydroelectric power penstocks. For chemical engineering field, manifolds are used in collecting or delivering chemical from unit to unit in the plant. In mechanical engineering, some

systems and plants use manifolds as well. Those systems and plants are for fuel distribution in the combustion chamber, thermal power plants and cooling system.

However, the most major used of manifold is on water supply system. Water supply system is a system that conveys potable water and meeting the fire protections for cities, homes, factories, school, hospital and other facilities. Interconnected series of manifolds, storage facilities and pumps are the major components in water supply system. Water is essential source of living whereby most of human activities are related to water like washing, cooking, commercial and industry processes, irrigation and other domestic used. Thus, water supply system need to be most effective to conveys good quality and enough quantity of water for these important uses of human activities every day without any failure. While the water is transported along the manifold, there will be losses occurred as the water flow through that is known as head loss.

Head loss consists of two type of loss which is major loss and minor loss. Determination of head losses is very important in pipe flow problem and also in designing a pumping system. Head loss in pipe flow system due to viscous effect due to friction will be termed as major head loss and indicated by  $h_{L\text{-major}}$ . While head loss in pipe flow system due to various piping components such as valves, fittings, elbows, contractions, enlargements, tees, bends and exits will be termed as minor head loss and indicated by  $h_{L\text{-minor}}$ . Therefore, the complete head loss or pressure loss in pipe flow will be summation of major head loss and minor head loss and indicated by  $h_L$ .

The term 'major' and 'minor' does not indicate the significance of the type of loss. Although the experts often account for a major portion of the head loss,

especially in process piping, the additional losses due to entries and exits, fittings and valves are traditionally referred to as minor losses. These losses represent additional energy dissipation in the flow, usually caused by secondary flows induced by curvature or recirculation.

The type of flow is important to study the effect of major loss to the total head losses. This is due to different type of flow that will affect the shear stress of a flow. If it is laminar flow, the effect of roughness of the surface is negligible and vice versa for turbulent flow. In turbulent flow, the energy loss due to a thin viscous layer does not exist on the pipe surface. There is a relationship between head loss and pipe length. The greater pipe length will produce higher friction loss. The larger pipe diameter will reduce the head loss. Friction will also affect the discharge. There is variation of velocity transversely the cross section. The discharge downstream from each outlet will effectively reduce if the outlets of manifold have regular spacing. Besides, the friction head loss is high and flow rate decreasing towards downstream, and means that manifold is not work effectively. While in considering minor loss in total head loss, the various piping components such as valves, fittings, elbows, contractions, enlargements, tees, bends and exits are taken into consideration. There is a relationship between minor loss and type of pipe components. Each type of piping components will give different effect to the losses in the pipe system. The manifold with different outlet spacing and area ratio of main pipe to outlet pipe diameter will produce different value of resistance coefficient ( $K$ ) thus will affect the losses. The uniformity from water discharge from the initial and after piping components is considered throughout this study.

Often the design engineers ignore the effect of minor loss in a pipe system since it is only small losses. This study takes minor losses into consideration of total

head loss and suggest a way to reduce it so that the effectiveness of the pipe system can be maximized. In order to achieve this, engineer requires being able to reliably work out the variation of pipe system design of different outlet spacing and area ratio of main pipe to outlet pipe diameter. The variation of pipe component used in the pipe design may produce different head loss. Knowledge and understanding of these variations would help to develop a better design solution to improve the problem and achieve uniform distribution. The solution can bring lots of benefits since there are various applications of manifolds.

Since manifold is very applicable in varies type of fields, many researchers around the world had put attention and effort to study about the practicability of the manifold. Some of the researchers explore the mechanics of manifold by using analytical while some of them validate formulae using experimental techniques. With both methods of study, it makes the theoretical descriptions of manifold flow more reliable and accurate for practical design purpose.

## **1.1 PROBLEM STATEMENT**

Water supply system conveys the water from a reservoir to the end user by distribution of pipes. To convey the water, multiple outlets pipe is widely used in various engineering fields. There is no much of awareness about hydraulic design of multiple outlets pipe. Design engineer commonly used the existing formula to design a water supply system. The formula is proven applicable for fix amount of flow from each outlet. However, the flow of water in a multiple outlets pipe is not equally distributed. In order to improve and enhance engineering calculation of minor losses, it is important to study the variation of area ratio and head loss along the multiple

outlets pipe. The experiment that will be conducted is expected to give a more accurate output which helps the engineers dealing with this multiple outlet design problem.

For this particular study, a physical model representing the multiple outlet pipes will be designed, fabricated and installed in front of the hydraulic laboratory in order to assess the discharge uniformity and minor losses of each outlets of the manifold. The design will consist of five different pipe diameters and different spacing of outlet pipes in order to study the variation in head loss mainly focused on minor losses and discharge along a multiple outlets Poly Vinyl Chloride (PVC) pipes.

## **1.2 OBJECTIVES**

The main objective of the study is to assess the variation in head losses mainly focuses on minor losses and discharge along a multiple outlets PVC pipe using physical model. The specific objectives are:

1. To investigate the minor losses along PVC pipe with different outlet spacing and area ratio of lateral pipe to main pipe diameter.
2. To determine the uniformity coefficient along PVC pipe with different outlet spacing and area ratio of lateral pipe to main pipe diameter.
3. To compare the losses along a pipe having the same length, diameter and discharge with and without outlets.
4. To determine the resistance coefficient,  $k$  of a multiple outlets pipes with various spacing and area ratio and compared with theoretical  $k$  value.

### **1.3 SCOPE AND LIMITATIONS OF THE STUDY**

The scopes of work that need to be carried out are as follows:

1. The study is focus on PVC pipes with dead ended manifold.
2. The head in the supply tank will be constant from 1.70 m.
3. The total length of the main pipe is 5.5 m.
4. The outlet pipe spacing is varies from 1.1, 2.2, 3.3 and 4.4 m and is equally spaced out between outlets.
5. Four different diameters combination for the main pipe and outlet pipes are used. The combinations are: (main pipe diameter follow by outlet pipes diameter)
  - i. 76.2 mm (3.0 inch) and 12.7 mm (0.5 inch)
  - ii. 50.8 mm (2.0 inch) and 12.7 mm (0.5 inch)
  - iii. 38.1 mm (1.5 inch) and 12.7 mm (0.5 inch)
  - iv. 25.4 mm (1.0 inch) and 12.7 mm (0.5 inch)
  - v. 12.7 mm (0.5 inch) and 12.7 mm (0.5 inch)
6. Discharge measurement is conducted by using volumetric method (graduated cylinder and stopwatch).
7. The head loss data will be obtained from the manometer reading installed at each before and after outlet pipe.

## **1.4 THESIS OUTLINE**

The thesis outline is to make a reader easier to understand the flow:

- **Chapter of Introduction**

This chapter is for project description. The term used in the study such as manifold, head loss, major and minor losses is explained in order to provide general idea of the study. Problem statement further discussed the problems in existing practice that become the main reason this study is conducted. The objectives of the study are listed as to achieve the required outcome of the study. Scope of works and limitations are all been listed in order to specifically described work planning to aim the main goal of the study.

- **Chapter of Literature Review**

This chapter is for the explanation of the issue related to the study based on previous research papers and journal. In this paper, literature review is divided into three subtopics which are losses in manifold including major and minor loss, uniformity in manifold and resistance coefficient. The previous formulae created in order to design a pipe system are also listed and discussed in this chapter. At the end of this chapter, the conclusion based on previous study and existing formulae is made in order to prove the relevance of this study.

- **Chapter of Methodology**

In this chapter, the model design and fabrication process is explained in detail in the form of pictures and sequence. The experimental procedure used throughout the study is listed in order to achieve the study goals. Few relationships are established by carrying out the design experiments. The

appropriate formulae and equipments used in this study are also been listed and described.

- **Chapter of Results and Discussions**

The result from the collected data is tabulated systematically to be analyzed in this chapter. The required parameters such as area ratio from different pipe diameter, minor losses from pressure head difference, uniformity coefficient based on the discharge, kinematic viscosity from the collected water temperature, Reynolds number and resistance coefficient are calculated and tabulated. The results are presented in appropriate graph and further discussion on the fluctuation of the result is being made.

- **Chapter of Conclusion and Recommendations**

The conclusion is to make a statement about finding from this project by comparing both theoretical and experimental of the study. The relevance of previous study is also discussed as to validate the results obtained from this study is correct. The recommendation is made to be taken into consideration for better improvement of the current project in future.

## **CHAPTER TWO**

### **LITERATURE REVIEW**

#### **2.0 BACKGROUND**

Manifolds have various applications in daily life engineering fields such as civil engineering, irrigation engineering, chemical engineering and mechanical engineering. The main objective of using manifold is to distribute a specific given discharge from the main inlet uniformly through multiple ports. The manifold is expected to function properly as to supply water with minimal value of head loss. In order to reduce the effect of head loss, the design should consider the suitable pipe size that given constraints of head loss and also flow distribution. Based on the result of head loss and discharge from the study, the value of resistance coefficient,  $K$  in manifold can be produced. Many formulas are developed to compute the loss for pipe without outlets yet there do not have any formula that can compute the loss in manifold accurately. Many of the researches study on head loss and flow distribution in manifold based on the developed theory for pipe without outlets and with some assumptions.

#### **2.1 LOSSES IN MANIFOLD**

Flowing fluid is categorized into two which are internal and external, depending on whether the fluid is forced to flow in a conduit or over a surface. Both internal and external flows exhibit very different characteristics. Internal flow is whereby the

conduit is completely filled with the fluid, and flow is primarily driven by a pressure difference. While open-channel flow is where the conduit is partially filled by the fluid and thus the flow is partially bounded by solid surfaces, as in an irrigation ditch where the flow is only driven by gravity forces. Friction is directly related to the pressure drop and head loss during flow through pipes and ducts. A typical piping system involves pipes of different diameters connected to each other by various fitting or elbows to route the fluid, valves to control the flow rate, and pumps to pressurize the fluid. Flow in a circular cross section usually referred as pipes used when the fluid is a liquid while for non-circular cross section as ducts is used when the fluid is a gas. This is due to pipes with circular cross section can withstand large pressure differences between inside and outside without undergoing significant distortion. A noncircular pipe is usually used for application involving heating and cooling system of buildings where the pressure difference is relatively small.

According to Bernoulli's Theorem, an element of fluid possess pressure energy when fluid flowing under pressure, kinetic energy due to the velocity and potential energy due to height  $z$  above datum. Daniel Bernoulli (1700-1782) states for a steady flow of a frictionless fluid along a streamline, the total energy per unit weight remains constant. While fluid flow from one point to another point of streamline, energy can be lost or supply by introducing pump. Total energy of two points in the system must equal to each other. According to Howland (1935), in order to balance the Bernoulli equation while head loss occurs, head loss term must bring into the right hand side of the equation in order to balance it.

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2 + h_f \quad (2.1)$$

where

$v$  = Velocity (m/s)

$P$  = Pressure (N/m<sup>2</sup>)

$g$  = Acceleration of gravity (m/s<sup>2</sup>)

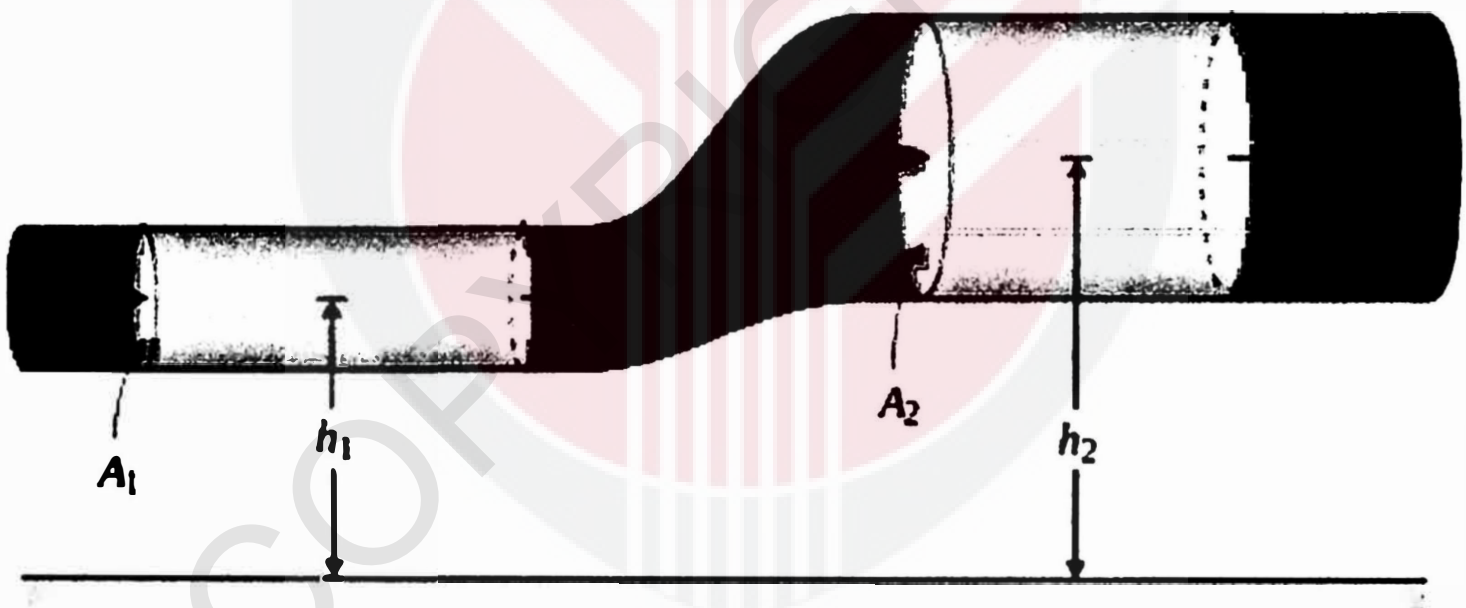
$z$  = Vertical elevation (m)

$\rho$  = Density of the liquid (kg/m<sup>3</sup>)

$h_f$  = Head loss due to friction (m)

Figure 2.1 explained that Bernoulli's Principle states that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or fluid's potential energy.

The principle mentioned that in a horizontal flow of fluid, points of higher fluid speed will have less pressure than points of slower fluid speed.



**Figure 2.1: Bernoulli's Principle Theory Explanation**

Each term of the equation is with unit "energy per unit weight". The unit can be interpreted to be a height by simplified it into meter (m) or foot (ft). The term head is referring to a height above a reference level in fluid flow analysis. Bernoulli's equation has some restriction in its applicability which are it only consider that the flow is in steady flow, constant density thus means that the fluid is incompressible and friction losses are negligible. However, fluid will experience

head loss when it flow through a pipe. Head loss in pipe depends on the properties of fluid transported, roughness of the pipe material, pipe condition and pipe appurtenances. Head loss in pipe can be categories into two types which are major and minor loss. Major loss mainly cause by friction while minor loss is due to local disturbances of flow in the manifold. The summation of major and minor loss is the total energy loss.

$$h_{\text{loss}} = h_{L \text{ Major}} + h_{L \text{ Minor}} \quad (2.2)$$

where

$h_{\text{loss}}$  = total head loss in the manifold system

$h_{L \text{ major}}$  = major loss due to friction

$h_{L \text{ minor}}$  = minor loss due to piping components

Major and minor losses will be further discussed in details. This discussion is mainly to differentiate between these losses. However, the main focus of this study is to determine the minor losses cause by local disturbances of flow in the manifold such as pipe bend, fitting, valve, and sudden enlargement and contraction of pipe size in the manifold.

### 2.1.1 Major Loss

The type of loss depends on the design of the whole system. A pipe system consists of a very long pipe and with little components, the major loss is significant than the minor loss. Howland (1953) presented a paper discuss design of perforated pipe for uniformity of discharge. He established an equation of the variation of pressure head

along a manifold with closed end from Bernoulli's equation when discharge was achieved uniformly. He produced the following total head loss equation final form.

$$h - h_0 = \frac{v_1^2}{2g} \left[ \frac{f_1 x_1}{(n+1)D} \left( \frac{x}{x_1} \right)^3 - \left( \frac{x}{x_1} \right)^2 \right] \quad (2.3)$$

where

$h$  = Pressure head at any point along the pipe

$h_0$  = Pressure head at the closed end of the pipe

$V_1$  = Velocity at entrance to the pipe

$h_L$  = Head loss due to pipe friction in the portion of the pipe between the point under consideration and the closed end

$x$  = Distance from the point to the closed end

$x_1$  = Length of the pipe

$f_1$  = Friction factor

$D$  = Pipe diameter

Anwar (1999) mentioned Darcy-Weisbach, Hazen-Williams and other well known friction formula can be used to calculate the head loss in a pipeline without outlets. Some of the researchers use Darcy-Weisbach and Hazen-Williams formula to compute the head loss in manifold. Some of the examples of researchers are Ramirez-Guzman and Manges (1971), Bezdek and Solomon (1978) and Mohammed et al. (2003). Ramirez-Guzman and Manges (1971) used similar method of analysis had done by Howland (1953). The initial conditions of the pipe were different between these two analyses. The pipe they considered was sloping while Howland considered the pipe was horizontal. Energy slope express by Ramirez-Guzman and Manges was based on Hazen-William equation. Ramizen-Guzman and Manges verified their equation with experimentally determined data and found out the

variation between it was up to 6.5%. Based on this result, it concluded that the above derived equation was suitable to use in field. The following equation was derived by them.

$$h = h_o - \frac{v_1^2}{2g} \left( \frac{X}{X_1} \right)^2 + \left[ \frac{v_1}{1.318C_H} \right]^{1.85} \frac{X_1}{2.85R^{1.17}} \left( \frac{X}{X_1} \right)^{2.85} + \frac{SX}{X_1} X_1 \quad (2.4)$$

Bezdek and Solomon (1978) emphasize that Hazen-William formula consist of limitation to compute the friction head loss. Viscosity of the following fluid was failed to account in Hazen-William formula. The results obtain for moderate Reynolds numbers and small pipe diameters based on the Hazen-William formula is comparatively inaccurate, Mohammed et.al. (2003) used Darcy-Weisbach equation in the experimental study. They found that Darcy-Weisbach equation is better for computing the manifold friction head loss compare to Hazen-William formula. The reason was because Darcy-Weisbach equation has less constraint and more advantages.

Major losses which are associated with frictional energy loss per length of pipe depend on the flow velocity, pipe length, pipe diameter and friction factor based on the roughness of the pipe and whether the flow is turbulent or laminar based on the Reynolds number. In a fully developed turbulent pipe flow, the major head loss is roughly proportional to square of flow rate. Darcy-Weisbach equation relates the major head loss due to fluid friction along given length of pipe to the average velocity. The equation below is valid for fully developed, steady and incompressible single-phase flow.

$$h_{L-Major} = f_D \cdot \frac{L}{2g} \cdot \frac{v^2}{D} \quad (2.5)$$

where

$h_{L-Major}$  = head loss due to friction (m)

$f_D$  = Darcy friction factor (dimensionless)

L = pipe length (m)

D = hydraulic diameter of pipe (m)

g = gravitational constant ( $m/s^2$ )

v = mean flow velocity (m/s)

The Darcy friction factor is a dimensionless quantity used in Darcy-Weisbach equation as the frictional losses in pipe system. This friction factor depends on the Reynolds number for the flow and the degree of roughness of the pipe's inner surface especially for turbulent flow while the friction factor of laminar flow is independent of roughness of the pipe's inner surface.

Since the study focuses mainly on minor losses, therefore, it is the main concern of this study.

### **2.1.2 Minor Loss**

Minor loss is the additional components such as valves and bend add to the overall head loss of the system. According to Henryk Kudela (2005), such losses are generally termed as minor losses, with the apparent implication being that the majority of the system loss is associated with the friction in the straight portions of the pipes, the major losses. He stated that in some cases of minor losses study, the minor losses itself can be greater than the major losses. This raised in minor losses may be resulting from the following conditions such as:

1. Pipe entrance or exit
2. Sudden expansion or contraction

3. Bends, elbows, tees and other fittings
4. Valves, open or partially closed
5. Gradual expansion or contraction

The form of Darcy's equation used to calculate minor losses of individual fluid system components is expressed by the equation

$$h_{L-Minor} = \frac{\Delta P}{\rho g} = K_L \frac{v^2}{2g} \quad (2.6)$$

where

$h_{L-Minor}$  = head loss due to pipe fittings (m)

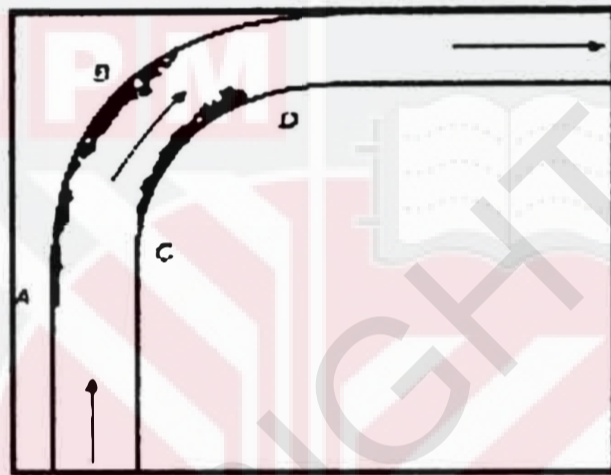
$K_L$  = resistance coefficient (dimensionless)

$v$  = mean flow velocity (m/s)

$g$  = gravitational constant ( $m/s^2$ )

Islam et.al (2016) presented a paper to study the minor losses coefficient of flexible pipes for different bend angles and different bend radius by experiment and simulation. The minor losses in a bend are due to flow separation on the curved walls and a swirling secondary flow arising from the centripetal acceleration. However, the theory is weak since the flow pattern in valves, bends and fittings are quite complex. The losses are usually measured experimentally and correlated with the pipe flow parameters. Minor loss in turbulent flow varies as the square of the velocity. An additional loss of head, apart from that due to fluid friction, takes place in the course of flow through pipe bend. Whenever a fluid flows in a curved path, there must be a force acting radially inwards on the fluid to provide the inward acceleration known as centripetal acceleration.

In a pipe bend illustrated in Figure 2.2, starting at some point A and rising to a maximum at some point B. There is also reduction of pressure near the inner wall giving a minimum pressure at C and subsequent rise from C to D. Therefore, fluid experiences an adverse pressure gradient in region between A and B and between C and D whereby the pressure increase in the direction of flow. Fluid particles in this region which have close proximity to the wall have low velocities cannot overcome the adverse pressure gradient and leads to a separation of flow from boundary and consequent losses of energy.



**Figure 2.2: Flow through a Bend Pipe**  
(Source: Islam et al., 2016)

Khan and Islam (1979) states that losses also take place due to a secondary flow in radial plane of the pipe because of a change in pressure in the radial depth of the pipe. This flow, in conjunction with the main flow, produces a typical spiral motion of the fluid which persists even for a downstream distance of fifty times the pipe diameter from the central plane of bend. This motion increases the local flow velocity and the velocity gradient at the pipe wall, and results in greater loss than that which occurs for the same rate of flow in a straight pipe of the same length and diameter. They found that Darcy-Weisbach equation is better for computing the minor losses in manifold. However, the minor losses will be varied according to the type of components used in the manifold. This is due to variation of resistance

coefficient, K value that gave the fluctuation to flow velocity in the pipe system thus affecting the head loss.

## 2.2 UNIFORMITY OF MANIFOLD

According to Franzini and Finnemore (1997), flow can be classified as that of an incompressible or compressible fluid. Liquid are treated as wholly incompressible fluids, since liquids are comparatively incompressible. Fluid flow can also be classified to laminar or turbulent flow. There are relative motions of fluid particles at a molecular scale for laminar flow. The fluid looks to move by sliding of laminations of extremely small thickness over adjacent layers. GH Dury et al. (1999) are two hydrologists that devised the models to study the relationship between discharge and other variables in a river. Bradshaw model described changes in river flow from source to mouth by considering pebble size and other variable while Dury considered the relationship between discharge and variables such as stream slope and friction. The following equations known as Continuity Equation implies on any incompressible fluid, such as liquid water:

$$Q = vA \quad (2.7)$$

where

$Q$  = Discharge ( $\text{m}^3/\text{s}$ )

$v$  = Flow velocity ( $\text{m}/\text{s}$ )

$A$  = Cross sectional area of the portion of the channel occupied by the flow ( $\text{m}^2$ )

and

$$Q = \frac{V}{t} \quad (2.8)$$

where

$Q$  = Discharge ( $\text{m}^3/\text{s}$ )

$V$  = Volume of water ( $\text{m}^3$ )

$t$  = Time (s)

Keller (1949) based on two factors which are inertia and friction to determine the flow characteristics in several types of manifold. The friction factor is left to be constant along the entire length of the manifold irrespective of the flow rate and assume as perfect the pressure recovery due to the axial deceleration of the flow. Keller neglected the pressure losses due to branching. The variation in width of a longitudinal slot in pipe would provide uniform outflow. The required change in cross-sectional area of a pipe is essential for the provision of uniform outflow through slots of constant width. Keller (1949) used two dimensionless ratios to define a manifold, which are:

$$\frac{L}{D} \text{ ratio} = \frac{\text{Active length of manifold}}{\text{Diameter of manifold}} \quad (2.9)$$

and the

$$\text{Area ratio} = \frac{d_{\text{lateral}}}{D_{\text{main}}} \quad (2.10)$$

where

$d_{\text{lateral}}$  = diameter of lateral pipe (m)

$D_{\text{main}}$  = diameter of main pipe (m)

Uniformity of flow distribution in a manifold can be described by the uniformity coefficient. Uniformity coefficient is defined as the ratio between last

outlet discharges to first outlet discharge. For ideal uniform flow distribution, the discharge of first outlet should be equal to the discharge of last outlet which means the uniformity coefficient should equal to one. Uniformity in a manifold is very important to maintain the flow distribution in pipe flow thus the discharge throughout the manifold will be uniformed.

$$\text{Uniformity Coefficient} = \frac{q_n}{q_1} \quad (2.11)$$

where

$q_n$  = Discharge at the last manifold outlet before the dead end,  $\text{m}^3/\text{s}$

$q_1$  = Discharge of the first manifold outlet,  $\text{m}^3/\text{s}$

### 2.3 RESISTANCE COEFFICIENT

Minor losses behave similarly to the major losses, where a device with a large K value leads to a high pressure loss. In general, a very sudden change to the flow path contributes to significant pressure loss. Energy losses are proportional to the velocity head of the fluid as it flows through various piping components. Experimental values for energy losses are usually reported in terms of a resistance coefficient, K as

$$h_L = K(v^2/2g) \quad (2.12)$$

The resistance coefficient is dimensionless as it represents a constant of proportionality between the energy loss and the velocity head. Minor losses is usually cause by sudden enlargement, gradual enlargement, sudden contraction, gradual contraction, exit loss, entrance loss, valves and fittings, and pipe bends. Robert L. Mott (2000) presents various K value for different piping components in the book of Applied Fluid Mechanics.

### 2.3.1 Sudden Contraction

Sudden contraction occurs when there is a sudden reduction of the cross-sectional area along the length of the pipe. Smooth transitions from the large to the smaller diameter cross-sectional area will produce more efficient design. The effective minimum cross section of the flow is smaller than that of the smaller pipe. Figure 2.3 illustrates the sudden contraction geometry in pipe where the section of minimum flow area occurs is known as vena contracta and the flow stream must decelerate and expand again beyond the vena contracta. Turbulence area labeled at c due to contraction and subsequent expansion generates the energy loss.

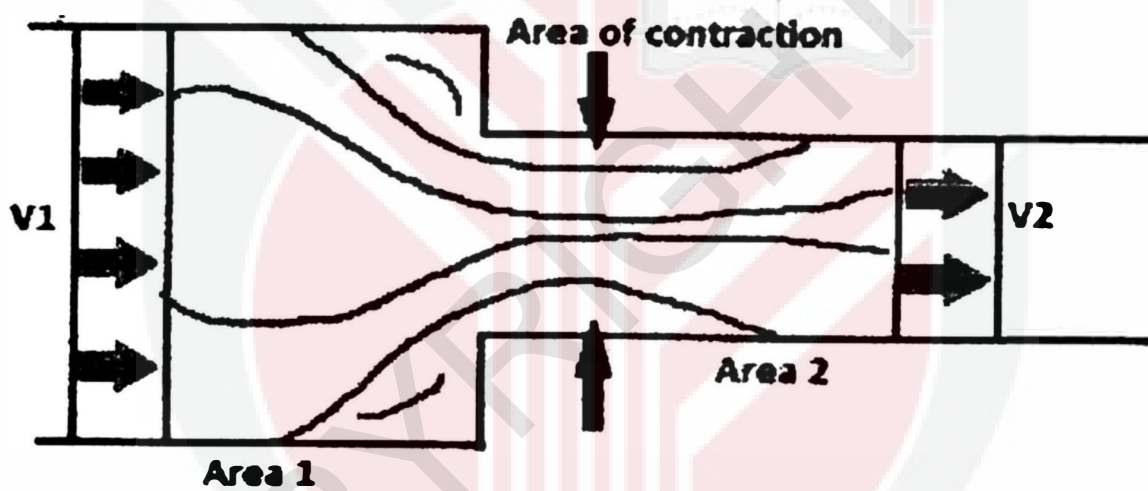


Figure 2.3: Sudden Contraction Geometry

**Table 2.1: Resistance Coefficient – Sudden Contraction**

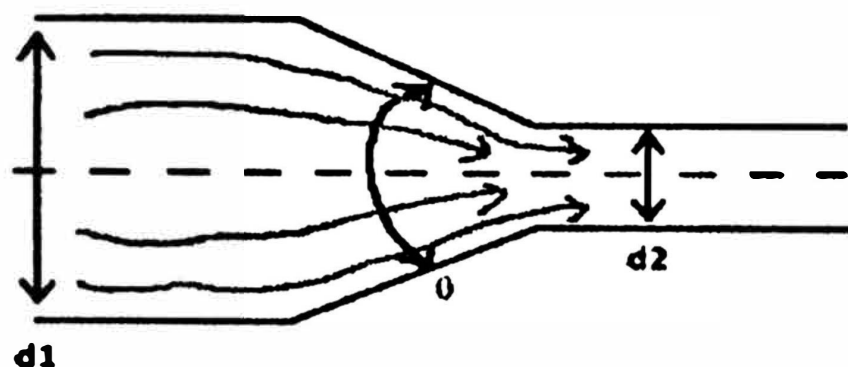
| $D_1/D_2$ | Velocity, $v_2$ |        |        |        |      |        |      |      |       |
|-----------|-----------------|--------|--------|--------|------|--------|------|------|-------|
|           | 0.6m/s          | 1.2m/s | 1.8m/s | 2.4m/s | 3m/s | 4.5m/s | 6m/s | 9m/s | 12m/s |
| 1.0       | 0.0             | 0.0    | 0.0    | 0.0    | 0.0  | 0.0    | 0.0  | 0.0  | 0.0   |
| 1.1       | 0.03            | 0.04   | 0.04   | 0.04   | 0.04 | 0.04   | 0.05 | 0.05 | 0.06  |
| 1.2       | 0.07            | 0.07   | 0.07   | 0.07   | 0.08 | 0.08   | 0.09 | 0.10 | 0.11  |
| 1.4       | 0.17            | 0.17   | 0.17   | 0.17   | 0.18 | 0.18   | 0.18 | 0.19 | 0.20  |
| 1.6       | 0.26            | 0.26   | 0.26   | 0.26   | 0.26 | 0.25   | 0.25 | 0.25 | 0.24  |
| 1.8       | 0.34            | 0.34   | 0.34   | 0.33   | 0.33 | 0.32   | 0.31 | 0.29 | 0.27  |
| 2.0       | 0.38            | 0.37   | 0.37   | 0.36   | 0.36 | 0.34   | 0.33 | 0.31 | 0.29  |
| 2.2       | 0.40            | 0.40   | 0.39   | 0.39   | 0.38 | 0.37   | 0.35 | 0.33 | 0.30  |
| 2.5       | 0.42            | 0.42   | 0.41   | 0.40   | 0.40 | 0.38   | 0.37 | 0.34 | 0.31  |
| 3.0       | 0.44            | 0.44   | 0.43   | 0.42   | 0.42 | 0.40   | 0.39 | 0.36 | 0.33  |
| 4.0       | 0.47            | 0.46   | 0.45   | 0.45   | 0.44 | 0.42   | 0.41 | 0.37 | 0.34  |
| 5.0       | 0.48            | 0.47   | 0.47   | 0.46   | 0.45 | 0.44   | 0.42 | 0.38 | 0.35  |
| 10.0      | 0.49            | 0.48   | 0.48   | 0.47   | 0.46 | 0.45   | 0.43 | 0.40 | 0.36  |
| $\infty$  | 0.49            | 0.48   | 0.48   | 0.47   | 0.47 | 0.45   | 0.44 | 0.41 | 0.38  |

(Source: King, H. W, et al., 1963)

### 2.3.2 Gradual Contraction

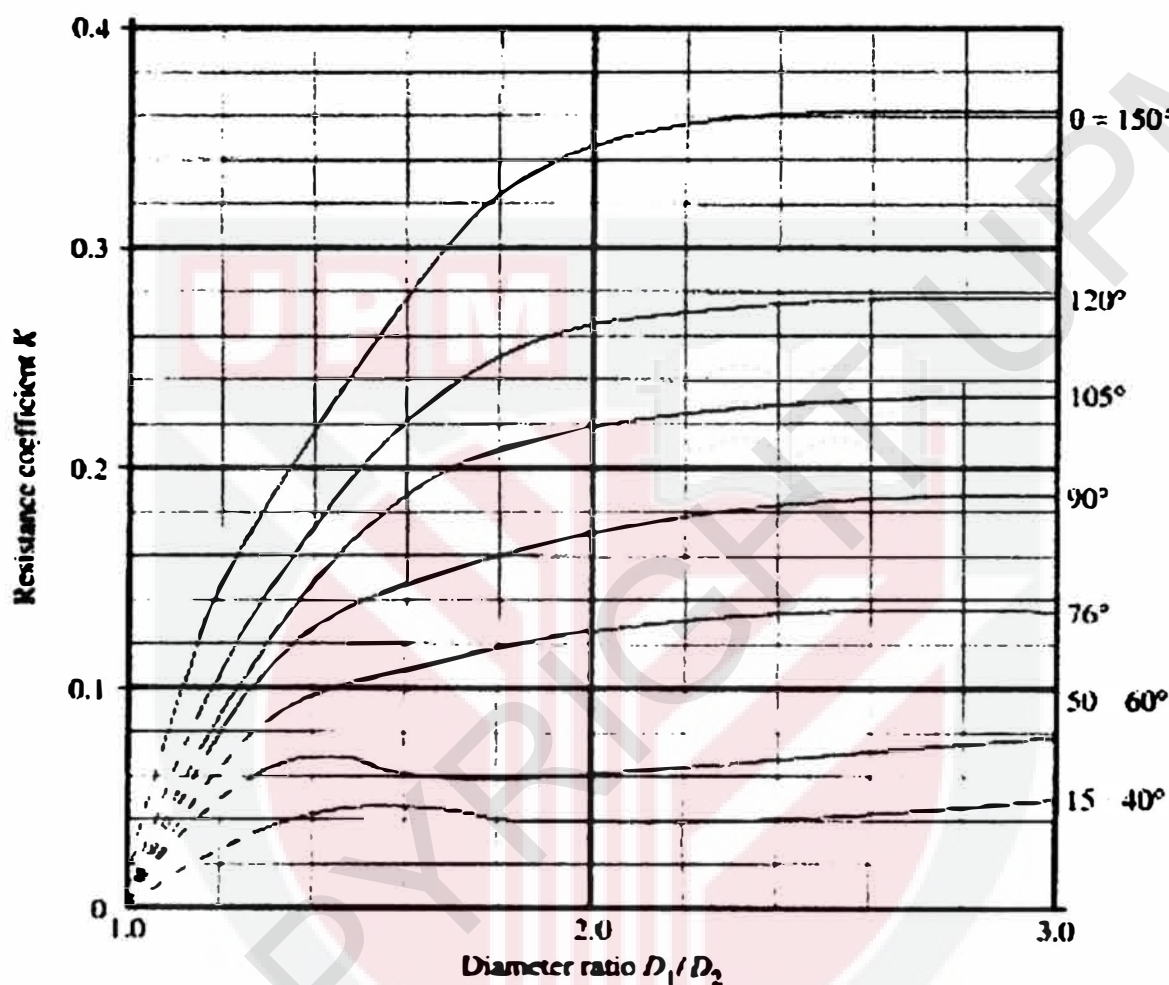
Sudden contraction can cause large energy loss which make the design is inefficient.

The energy loss can be reduced substantially by making the contraction more gradual. Figure 2.4 shows the gradual contraction formed by a conical section between two diameters with sharp breaks at the junctions. Angle  $\theta$  is known as cone angle.



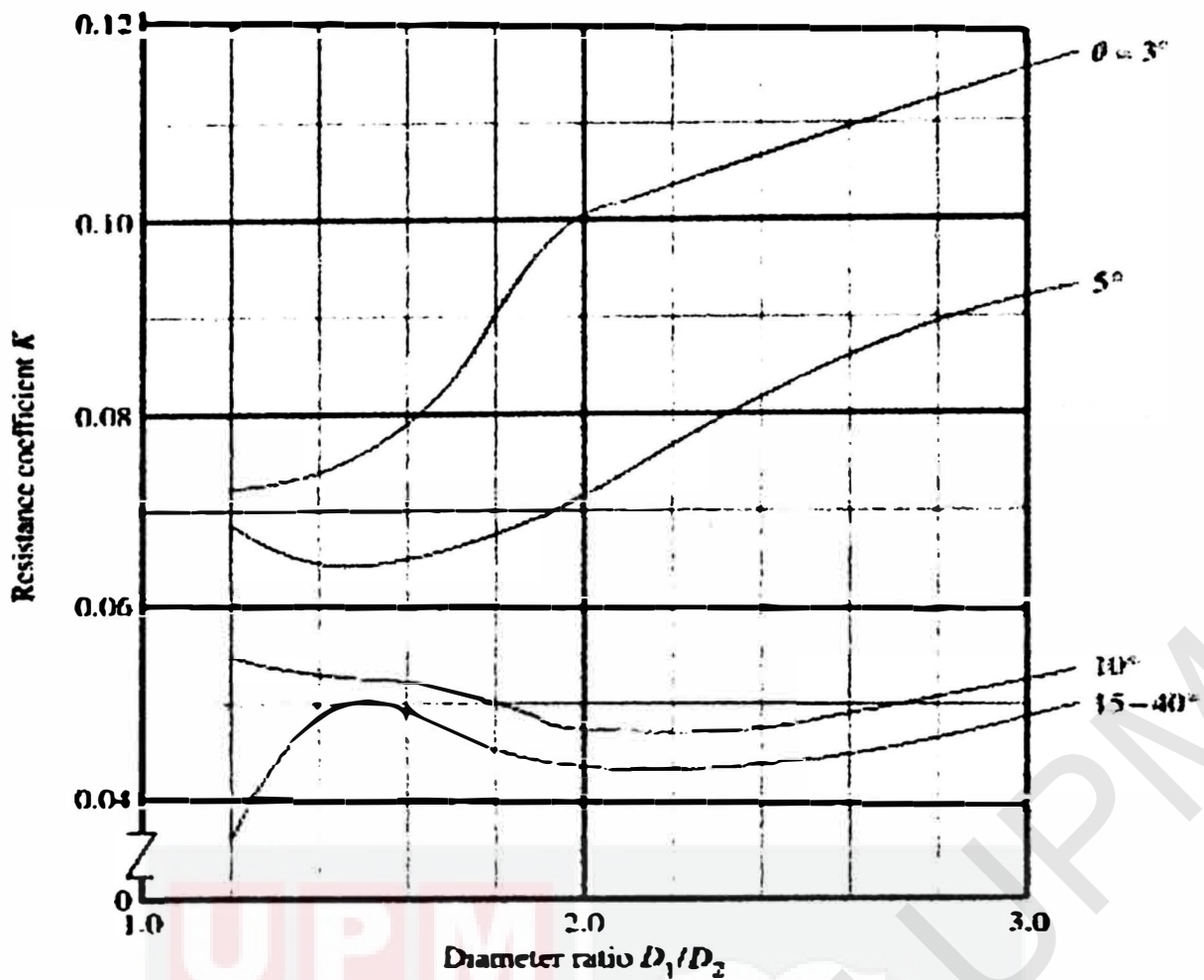
**Figure 2.4: Gradual Contraction Geometry**

Figure 2.5 shows the data for the resistance coefficient versus diameter ratio for several values of the cone angle. The resistance coefficient is based on the velocity head in a smaller pipe after the contraction. However, these data only valid for Reynolds number greater than  $1.0 \times 10^5$  or known as turbulent flow. K values for angles range from  $15^\circ$  to  $40^\circ$  is 0.05 or less which a very low value while for angle large as  $60^\circ$ , K is less than 0.08.



**Figure 2.5: Resistance Coefficient – Gradual Contraction**  
(Source: Robert L. Mott., 2000)

The resistance coefficient increases as the cone angle of the contraction reduces below  $15^\circ$  as shown in Figure 2.6. This increment of K is due to the effects of local turbulence caused by flow separation and pipe friction. Smaller cone angles which produce longer transition between two diameters will increase the friction losses.



**Figure 2.6: Resistance Coefficient – Gradual Contraction**  
(Source: Robert L. Mott., 2000)

### 2.3.3 Valves and Fittings

Resistance coefficient of every valves and fittings used in a pipe system will produce variation in energy loss to the system. It is important to determine the resistance data for the particular type and size chosen because the resistance is depending on the geometry of the valve or fittings. Valves is usually used as to control the flow amount to the system such as globe valves, angle valves, gate valves and butterfly valves. While fittings will direct the flow path or cause changes in the size of the flow path including elbows, tees, reducers, nozzles and orifices.

Different method are used to determine the resistance coefficient in valves and fitting whereby the value K is reported in the form

$$K = (L_e/D)f_T \quad (2.13)$$

where

K = resistance coefficient (dimensionless)

$L_e$  = length of straight pipe of the same nominal diameter

$D$  = inside diameter of the pipe

$f_T$  = friction factor in pipe

A constant value of  $L_e / D$  which known as equivalent length ratio is produce as in Table 2.2 for each type of valves and fittings.

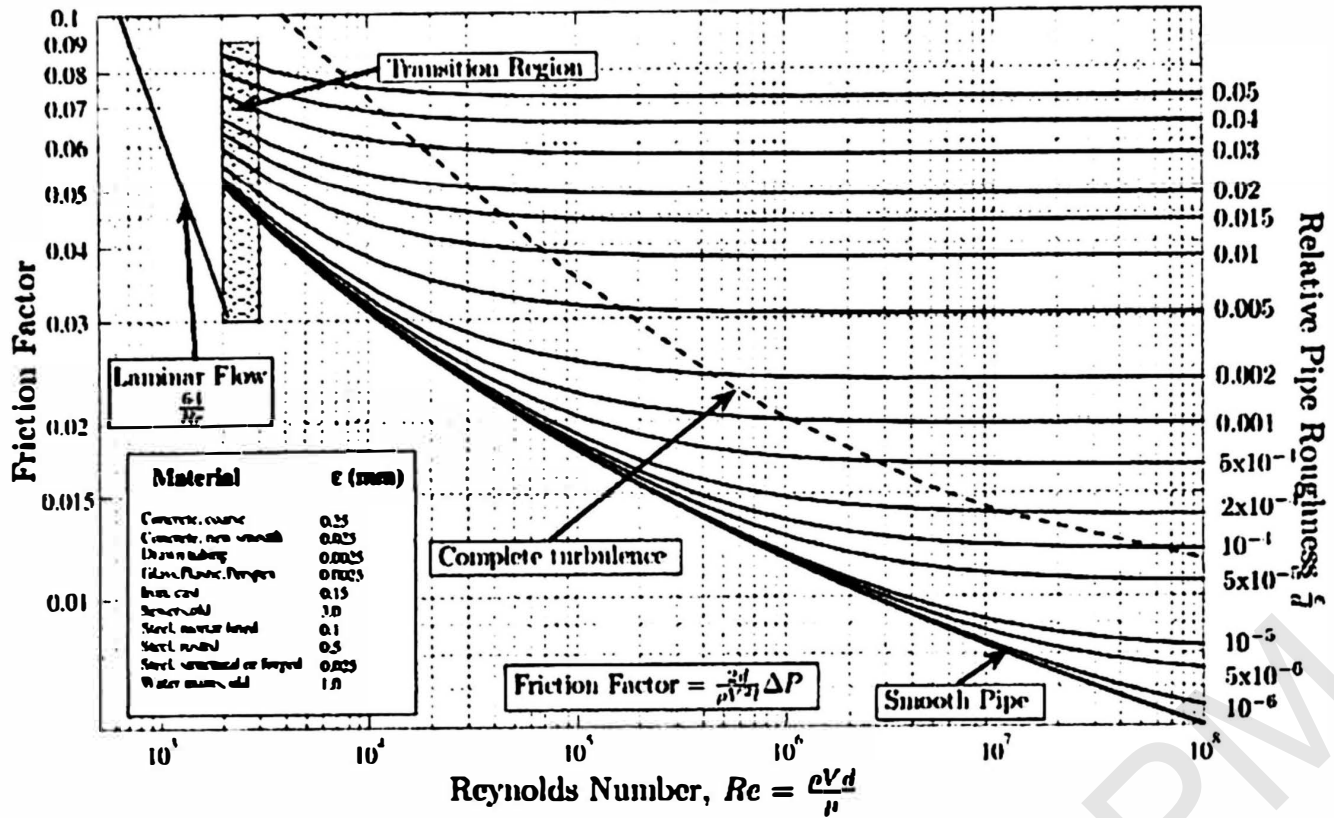
**Table 2.2: Resistance in Valves and Fittings Expressed as Equivalent Length in Pipe Diameter,  $L_e/D$**

| Type                                    | Equivalent Length in Pipe Diameters, $L_e / D$ |
|---|--|
| Global valve – fully open               | 340  |
| Angle valve – fully open                | 150  |
| Gate valve – fully open                 | 8  |
| Gate valve – $3/4$ open                 | 35   |
| Gate valve – $1/2$ open                 | 160  |
| Gate valve – $1/4$ open                 | 900  |
| Check valve – swing type                | 100  |
| Check valve – ball type                 | 150  |
| Butterfly valve – fully open            | 45   |
| Foot valve – poppet disc type           | 420  |
| Foot valve – hinged disc type           | 75   |
| 90° standard elbow                      | 30   |
| 90° long radius elbow                   | 20   |
| 90° street elbow                        | 50   |
| 45° standard elbow                      | 16   |
| 45° street elbow                        | 26   |
| Close return bend                       | 50   |
| Standard tee – with flow through run    | 20   |
| Standard tee – with flow through branch | 60   |

(Source: Crane Valves, Joliet, IL)

The term  $f_T$  is the friction factor in pipe which taken in the zone of complete turbulence. In the Moody diagram of Figure 2.7, the zone of complete turbulence lies in the far right area where the friction factor is independent of Reynolds number. Dashed line running across the diagram divides the zone of complete turbulence from transition zone to the left.

Moody Diagram



**Figure 2.7: Moody's Diagram**  
(Source: Retrieved from the Engineering Toolbox)

Table 2.3 lists the variation of  $f_T$  for standard nominal size. The variation of  $f_T$  cause the value of the resistance coefficient,  $K$  also varies. However, this method of findings  $K$  value will only valid if the flow in the pipe is in the zone of complete turbulence.

**Table 2.3: Friction Factor in Zone of Complete Turbulence for New, Clean Commercial Steel Pipe**

| Nominal Pipe Size (in) | Friction Factor, $f_T$ | Nominal Pipe Size (in) | Friction Factor, $f_T$ |
|------------------------|------------------------|------------------------|------------------------|
| 1/2                    | 0.027                  | 3 1/2, 4               | 0.017                  |
| 3/4                    | 0.025                  | 5                      | 0.016                  |
| 1                      | 0.023                  | 6                      | 0.015                  |
| 1 1/4                  | 0.022                  | 8 - 10                 | 0.014                  |
| 1 1/2                  | 0.021                  | 12 - 16                | 0.013                  |
| 2                      | 0.019                  | 18 - 24                | 0.012                  |
| 2 1/2, 3               | 0.018                  |                        |                        |

(Source: Robert L. Mott., 2000)

## **2.4 SUMMARY OF LITERATURE REVIEW**

The conclusion is made based on the developed theories from previous research paper and journals to provide relevance connection between existing theory and the experiment conducted to assess the minor losses in a pipe with different diameters and multiple outlets.

According to Daniel Bernoulli (1700-1782), energy can be loss or supply by introducing pump when a fluid flow from one point to another point of streamline. The increase in the speed of a fluid will occur simultaneously with a decrease in pressure or fluid's potential energy. This theory is related to the conducted experiment for pipe without outlet which the water pressure at the starting is expected to be lower compared to the last outlet due to higher velocity at the beginning of the manifold. As the water move along the manifold, the pressure started to rise with the decrease in velocity. On the other hand, for a pipe with various outlets, the pressure is not constant along the manifold due to disturbance of flow happened at each outlet.

The major and minor losses occur from the effect of friction in a pipe and effect of various piping components respectively. Since the study focuses mainly on minor losses, therefore it is the main concern of this study. The piping component that is taken into consideration to calculate theoretical  $k$  is only one type of fitting installed in the pipe which is standard tee with flow through branch. However, the fabricated manifold consists of many piping components such as reducers and valves that also contribute to the minor losses.

Franzini and Finnemore (1997) classify fluid into incompressible and compressible fluid while liquid is treated as incompressible fluids. Keller (1949)

used dimensionless ratios as to define a manifold which is by using area ratio of lateral pipe to main pipe diameter. For ideal uniform flow distribution, the discharge of first outlet should be equal to the discharge of the last outlet thus defined as uniformity coefficient. This study will show which area ratio pipe that may produce the most uniform flow with the uniformity coefficient that approximately equal to 1.0.



## CHAPTER THREE

### METHODOLOGY

#### 3.0 BACKGROUND

A physical model of different diameters and multiple outlets pipe designs was fabricated. The diameter of the main pipe and spacing between the outlet pipes is manipulated to achieve the objectives of this study. Few relationships are established by carrying out the designed experiments such as:

1. Variation of the pressure head and minor loss along PVC pipe with different outlet spacing and area ratio.
2. Variation of the uniformity coefficient along PVC pipe with different outlet spacing and area ratio.
3. Variation of pressure head along PVC pipe having same length, diameter and discharge with and without outlets.
4. Variation of resistance coefficient,  $k$  along PVC pipe with various spacing and area ratio.

The results obtained from the experiment will be analyzed by using suitable formulae.

$$v = \frac{Q}{A} \quad (2.7)$$

Where

$Q$  = Discharge ( $\text{m}^3/\text{s}$ )

$v$  = Velocity of the flow ( $\text{m/s}$ )

**A = Area of the pipe (m)**

$$Q = \frac{V}{t} \quad (2.8)$$

where

**Q = Discharge (m<sup>3</sup>/s)**

**V = Volume of water (m<sup>3</sup>)**

**t = Time (s)**

$$\text{Area ratio} = \frac{d_{\text{lateral}}}{D_{\text{main}}} \quad (2.10)$$

where

**d<sub>lateral</sub> = Diameter of lateral pipe (m)**

**D<sub>main</sub> = Diameter of main pipe (m)**

$$\text{Uniformity coefficient} = \frac{q_n}{q_1} \quad (2.11)$$

where

**q<sub>n</sub> = Discharge of the last manifold segment before the dead end (m<sup>3</sup>/s)**

**q<sub>1</sub> = Discharge of the first manifold segment (m<sup>3</sup>/s)**

$$h_{L-\text{minor}} = K \frac{v^2}{2g} \quad (2.12)$$

where

**h<sub>L-minor</sub> = Minor loss (m)**

**K = Minor losses coefficient (dimensionless)**

**v = Velocity of the flow (m/s)**

**g = Gravitational force, 9.81 (m/s<sup>2</sup>)**

$$K = (L_e/D)f_T \quad (2.13)$$

where

$K$  = Resistance coefficient (dimensionless)

$L_e$  = Length of straight pipe of the same nominal diameter (m)

$D$  = Inside diameter of the pipe (m)

$f_T$  = Friction factor in pipe

$$A = \frac{\pi d^2}{4} \quad (3.1)$$

where

$\pi = 3.142$

$d$  = Diameter of the pipe (m)

$$Re = \frac{vD}{\nu} \quad (3.2)$$

where

$Re$  = Reynolds number

$v$  = velocity (m/s)

$D$  = Diameter of the pipe,  $D$  (m)

$\nu$  = Kinematic Viscosity,  $(m^2/s) \times 10^{-6}$

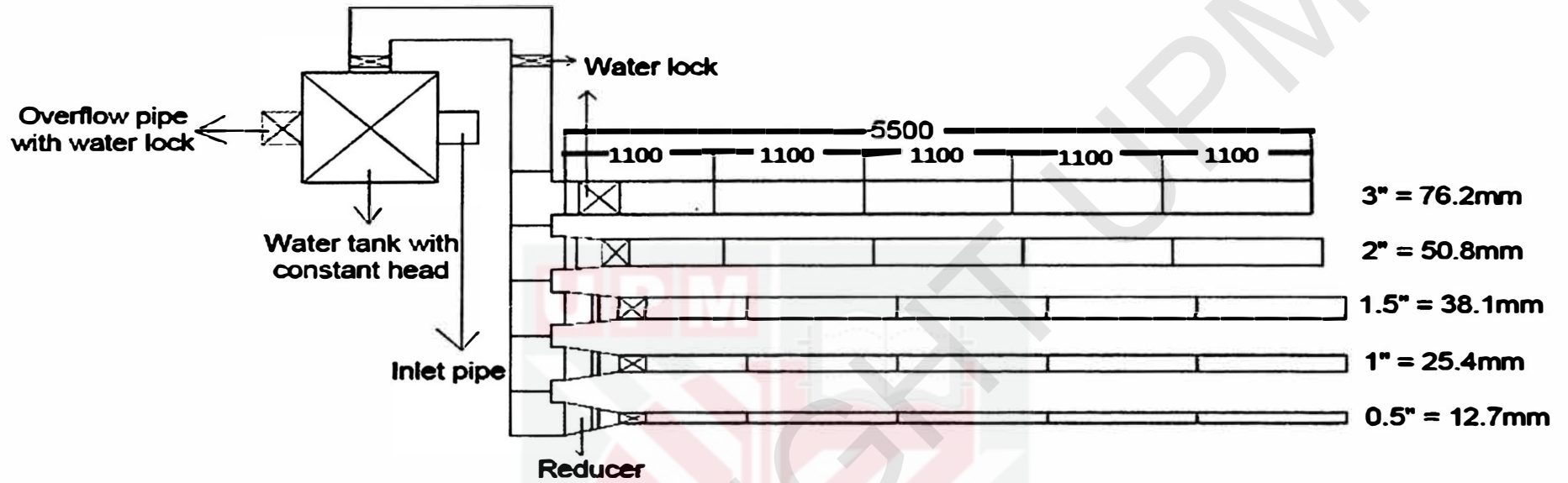
### 3.1 MODEL DESIGN AND FABRICATION

The overall pipe system consists of three main components which are water supply tank, valves and manifold pipes. The water supply tank is originally available in front of the Hydraulic Laboratory, Faculty of Engineering. The water supply tank and the support are made of steel and painted to prevent rust. The valves that are

used to control the water flow into the manifold pipes are made from PVC. The manifold and all connected piping are made from PVC pipes. The manifold design is developed using Auto-Cad software as shown in Figure 3.1 and Figure 3.2.

### **3.1.1 Multiple Outlet Pipe (Manifold) Design**

The pipe used in this study is PVC for both main and lateral pipe. Five different area ratio of the manifold are used to determine the relationship between area ratio and variation of minor loss and discharge flow in the manifold. Five different diameters of the main pipe used are 12.7 mm (1/2 inch), 25.4 mm (1 inch), 38.1 mm (1 ½ inch), 50.8 mm (2 inch) and 76.2 mm (3 inch). 12.7 mm diameter PVC pipe is used for every lateral pipe thus making area ratio of lateral to main pipes is 1.0, 0.5, 0.33, 0.25 and 0.17. Every lateral pipe is controlled by a valve. The spacing between lateral pipes is fixed at every 1.1 m throughout 5.5 m total pipe length.

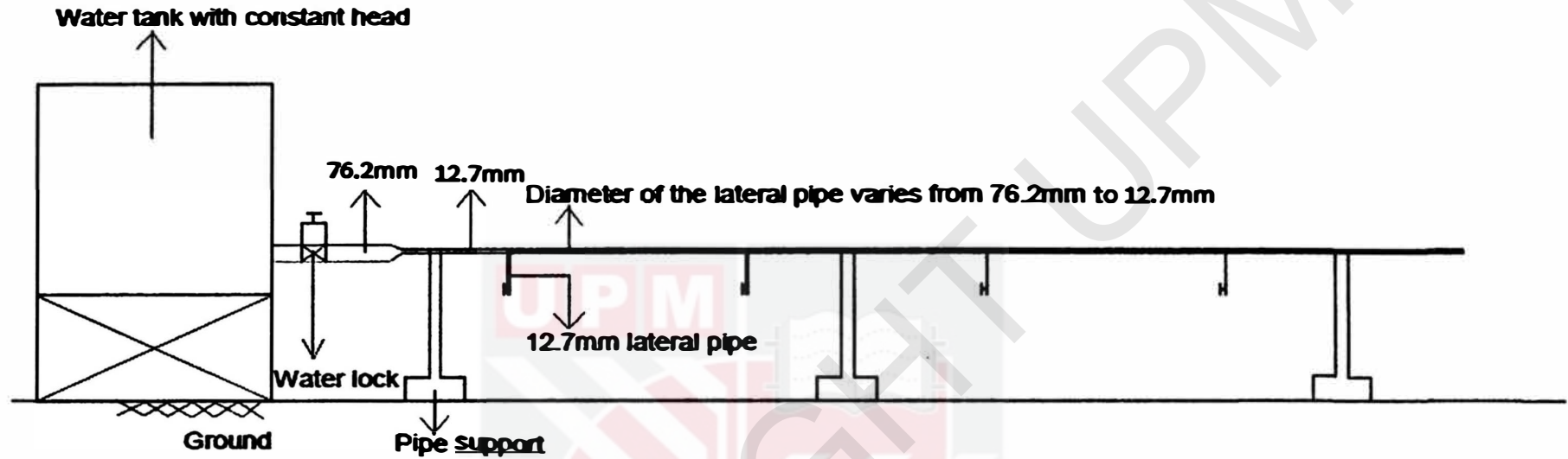


**PLAN**

**Note:**

1. All dimension are in millimeter (mm)
2. This section drawn is not to scale
3. Dimension for reducers
  - a. 76.2mm to 50.8mm
  - b. 76.2mm to 38.1mm
  - c. 76.2mm to 25.4mm
  - d. 76.2mm to 12.7mm

**Figure 3.1: Plan View of the Manifold**



### ELEVATION

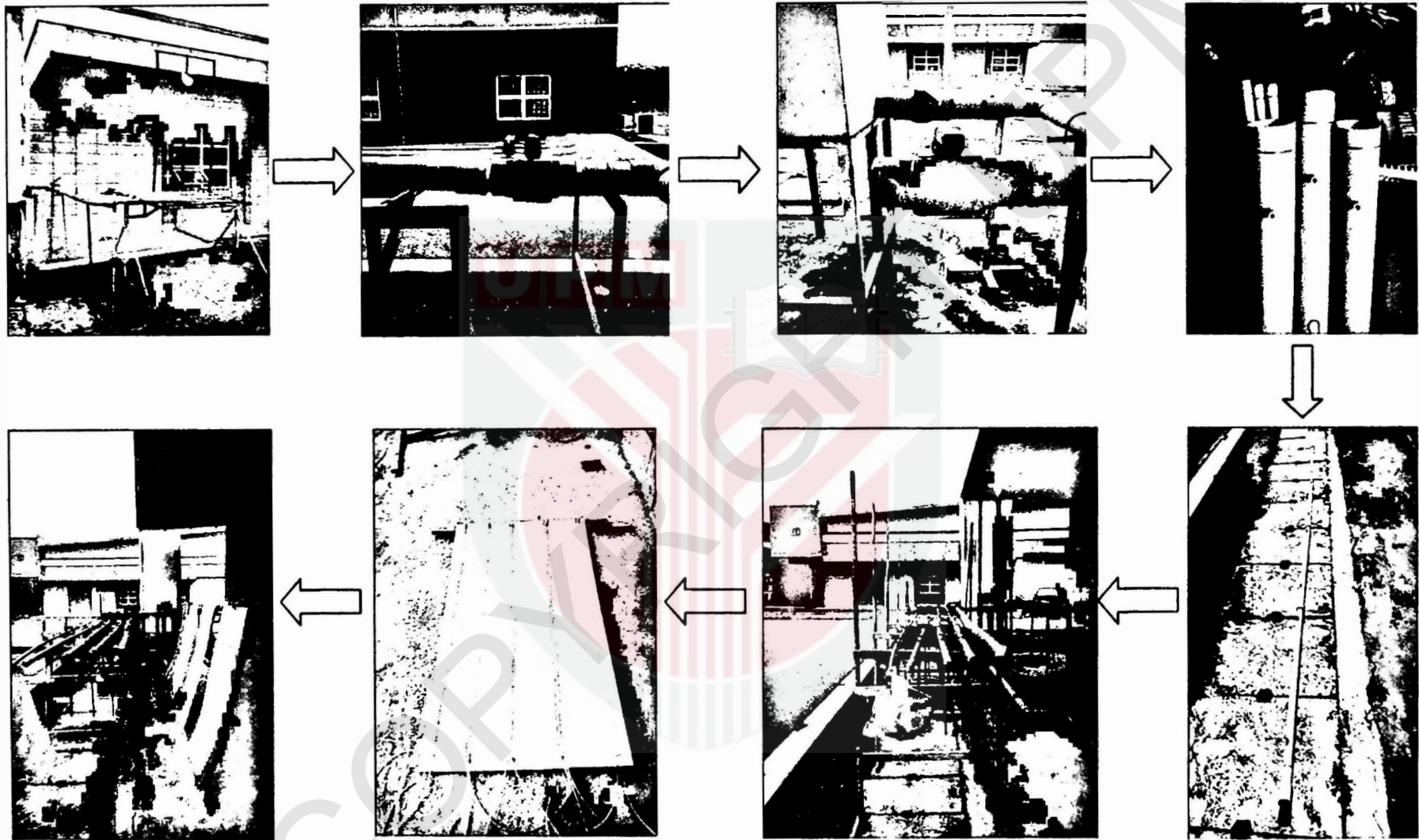
#### Note:

4. All dimension are in millimeter (mm)
5. This section drawn is not to scale
6. Dimension for reducers
  - a. 76.2mm to 50.8mm
  - b. 76.2mm to 38.1mm
  - c. 76.2mm to 25.4mm
  - d. 76.2mm to 12.7mm

**Figure 3.2: Elevation View of the Manifold**

### **3.1.2 Multiple Outlet Pipe (Manifold) Fabrication Process**

The manifold is firstly designed using the Auto-Cad software before the fabrication process begins.. Auto-Cad design outcome is as shown in Figure 3.1 and Figure 3.2. The fabrication process is started right after the software design is completed. First of all, the existing pipe condition at the hydraulic laboratory is being checked before the pipe is connected to the existing pipe. This is to prevent any defect happens at the pipe connection after the fabrication process. Then, the PVC pipe is cut based on required length and a hole is drilled at the PVC pipe for the manometer connection. Manometer pipe is connected from the PVC pipe to the board for the data collection purposes. After the fabrication process, the first run test is conducted to determine the defect at the fabricated manifold. Due to fabrication problem, there are leakage occurred at some points in the manifold system that need to be repaired. The real experiment and data collection only started after the leakage is fixed. The manifold fabrication process is explained in Figure 3.3.



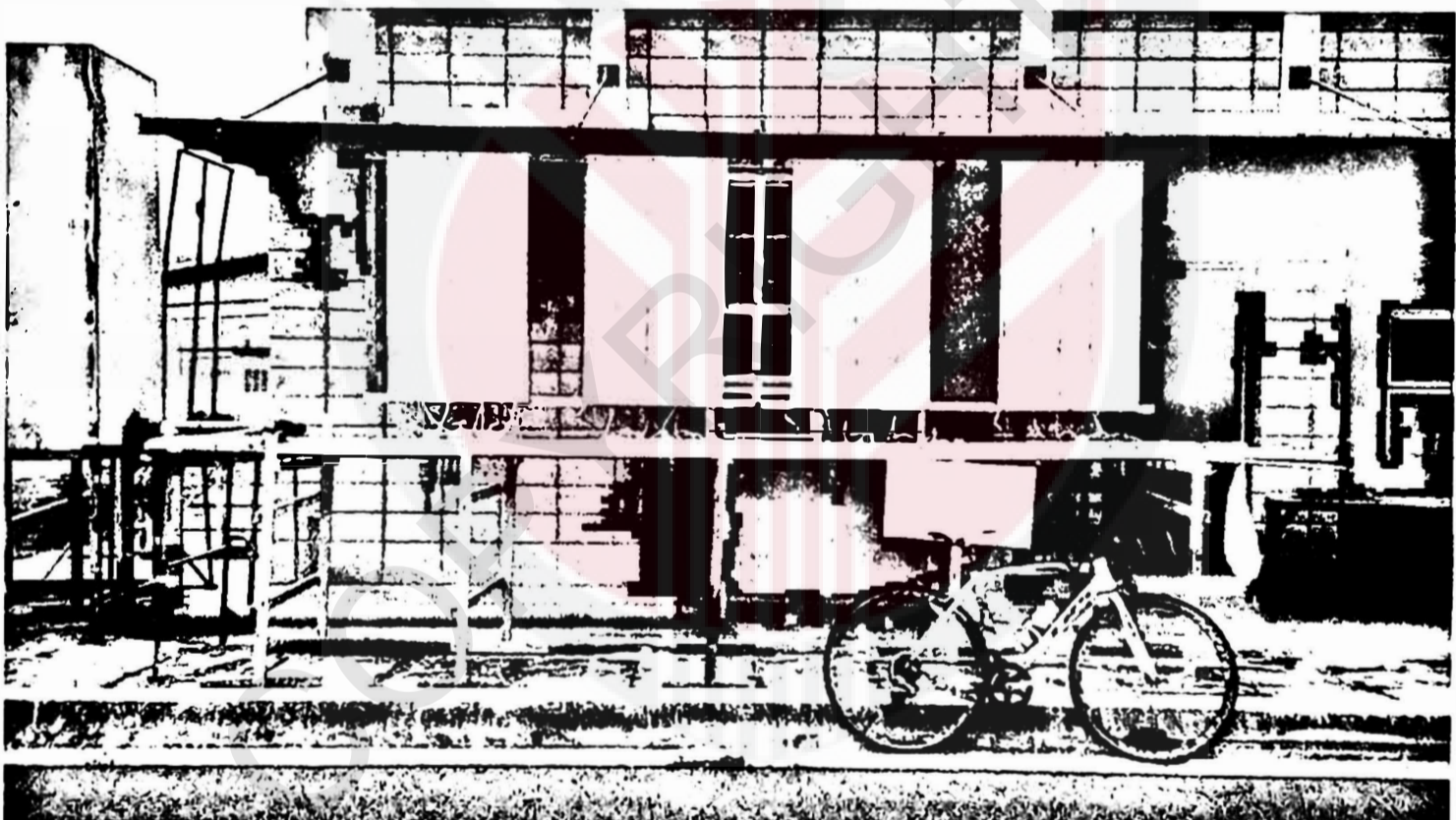
**Figure 3.3: Manifold Fabrication Process**



**Figure 3.4: Leakage in Pipe**



**Figure 3.5: Repairing of the Leakage Pipe**



**Figure 3.6: Completed Manifold**

### **3.1.3 Water Tank**

The purpose of the water tank is to supply water to the whole piping system. The dimension of the water tank is 2.50 m height, 1.0 m length and 1.0 m width. The water tank has three overflow outlets which are used to control the water levels in the tank and it is connected to the pipe system to supply water.

The positions of the three overflow outlets are located at depth 1.20 m, 1.70 m and 2.20 m measured from the center of the connected pipe to the tank. The first and the third overflow outlet are closed because it is not use in the study. The second overflow outlet at height of 1.70 m is used. The overflow outlet is controlled by a valve and connected to a discharge pipe of 76.2mm diameter (3.0 inch) to keep the constant water level in the tank. The discharge pipe is then connected to the main water storage located at the back of the hydraulic laboratory in order to avoid water wastage. The water source that supplied to the manifold is from the elevated tanks at the hydraulic laboratory. The diameter of the inlet pipe is 100 mm and the elevated tank is supported by steel structure. The height of the elevated water tank from the ground base is 1.05 m. Figure 3.8 shows the elevated water tank and the overflow outlets used to control the water level inside the tank.



**Figure 3.7: Existing Water Tank**

### 3.1.4 Measuring Devices

As the water flows through the manifold, the pressure will drop. Therefore pressure at the end of the manifold will be the lowest. It is important to determine the pressure drop, therefore, the variation of pressure drop for different spacing and area ratio is measured using the manometer. A manometer is a plastic tube placed vertically to allow the fluid to flow in the tube. It is installed before and after each lateral outlet to determine the losses occurred by the outlets. A scale ruler is installed at every manometer board for the minor loss data reading purpose. The manometer setup is shown in Figure 3.8.



**Figure 3.8: Manometer Setup**

Based on equation 2.8, the volume of water discharge with the time taken should be known to identify the discharge of water. Volumetric method is used to determine the discharge at every outlet. The volume of water is measured by scaled container while the time taken is constant to 30 seconds by using the stop watch. A

thermometer is used in this study to measure the water temperature during the experiment. This data is useful to calculate dynamic viscosity,  $\nu$ .

### 3.2 EXPERIMENTAL DESIGN

The experiments are conducted three times each in order to get the average value and improve the accuracy of the result. The data taken for each experiment are the volume, time and head loss. The experimental design is as below:

**Table 3.1: Experimental Details**

| Experiments     |                    |   | No. of experiment conducted |   |           |
|-----------------|--------------------|---|-----------------------------|---|-----------|
| Water Level (m) | Outlet spacing (m) | Area Ratio ( $d_{\text{lateral}} / D_{\text{main}}$ ) | 1                           | 2 | 3         |
| 1.7             | 1.0, 2.0, 3.0, 4.0 | 0.17  | 4                           | 4 | 4         |
|                 |                    | 0.25  | 4                           | 4 | 4         |
|                 |                    | 0.33  | 4                           | 4 | 4         |
|                 |                    | 0.50  | 4                           | 4 | 4         |
|                 |                    | 1.00  | 4                           | 4 | 4         |
|                 |                    | <b>TOTAL</b>  |                             |   | <b>60</b> |

### 3.3 EXPERIMENTAL PROCEDURE

1. The first experiment was conducted for a main pipe of 76.2 mm diameter and lateral pipe of 12.7 mm diameter. All the valves located at the water supply tank and the manifold system is closed.
2. The water supply tank is filled by opened the main valve inside the hydraulic laboratory until it reached the required head of 1.7 m. When the overflow discharge pipe that is connected to the water tank started discharging water, it signifies a constant head is reached.

3. The global valve at main pipe and first lateral pipe is opened to allow water flows through the manifold (76.2 mm main pipe and 12.7 mm lateral pipe). While valves connected to the other pipes are remain closed.
4. The manometer reading before and after the first lateral pipe is recorded and the water discharge is collected. The water discharge from lateral pipe is collected by using the scaled container and stopwatch. The volume of the water is collected within constant time of 30 seconds. Water temperature is measured by using a thermometer.
5. The global valve at first lateral pipe is then closed and outlets spacing are adjusted to 2.20 m and Step 3 and 4 is repeated.
6. Step 3 and 5 is repeated for others spacing 3.30 m and 4.40 m.
7. The global valves at lateral pipes are then closed to prevent the water to discharge out of the manifold. The manometer reading throughout the main pipe is recorded. This manometer reading will be compared to manifold having the same length and diameter but with and without outlet.
8. Step 3 to 7 is repeated for remaining four other combinations of manifold main pipe to lateral pipe diameter which is 50.8 mm to 12.7 mm, 38.1 mm to 12.7 mm, 25.4 mm to 12.7 mm and 12.7 mm to 12.7 mm.
9. Each experiment is repeated three times to get the average value and increase the accuracy of the results.
10. The result obtained from the experiments are analyzed and tabulated in table.

## **CHAPTER FOUR**

### **RESULTS AND DISCUSSIONS**

#### **4.0 BACKGROUND**

The study is conducted to study the variation in head losses mainly focused on minor loss and discharge along a multiple outlets PVC pipe. Results obtained from the experiments are recorded, tabulated and analyzed. Different figures are plotted to demonstrate the governing variables including area ratio, uniformity coefficient, resistance coefficient and Reynolds number. Moreover, the results are further discussed to provide details on the impact of the variables on manifold hydraulics.

The experiments planned to study five different values for area ratio which are 0.17, 0.25, 0.33, 0.50 and 1.00. However, during the experiments, the water supply was not enough to reach to the end of the manifold in large area ratio pipe which is 1.00. Due to this reason, analysis is mainly discussed on area ratio of 0.17, 0.25, 0.33 and 0.50. The collected data during the experiments are summarized in Appendix A. The results obtained are analyzed and summarize in Table 4.1 to 4.6 which show part of the result and the remaining result are shown in Appendix B. The sample calculation of the result is presented in Appendix C. Table 4.1 shows the area ratio based on different pipe diameter combination of lateral pipe to main pipe diameter.

**Table 4.1: Area Ratio Based on Different Pipe Diameter Combination**

| <b>Experiment</b> | <b>Main Pipe Diameter, D (m)</b> | <b>Outlet Pipe Diameter, d (m)</b> | <b>AR (d/D)</b> |
|-------------------|----------------------------------|------------------------------------|-----------------|
| D = ½", d = ½"    | 0.0127                           | 0.0127                             | 1.00            |
| D = 1", d = ½"    | 0.0254                           | 0.0127                             | 0.50            |
| D = 1 ½", d = ½"  | 0.0381                           | 0.0127                             | 0.33            |
| D = 2", d = ½"    | 0.0508                           | 0.0127                             | 0.25            |
| D = 3", d = ½"    | 0.0762                           | 0.0127                             | 0.17            |

Area ratio is based on the combination of lateral pipe to main pipe diameter. Since the lateral pipe used in this study is constant of 0.0127 m thus the area ratio varies only due to various main pipe diameters. The area ratio of the pipe decreases with the increases of the diameter of main pipe. This shows that the relationship of area ratio and main pipe diameter is inversely proportional.

#### **4.1 VARIATION OF PRESSURE HEAD AND MINOR LOSS ALONG PVC PIPE WITH DIFFERENT OUTLET SPACING AND AREA RATIO**

The study shows that the pressure head along the manifold varies with different outlet spacing and area ratio. The discussion on variation of pressure head and minor loss along manifold is focused on two variables which are at different outlet spacing in same area ratio pipe and same outlet spacing in different area ratio pipe. Table 4.2 shows the data taken during the experiments and minor loss is calculated by the difference in pressure head before and after each outlet.

**Table 4.2: Pressure Head and Minor Loss Data**

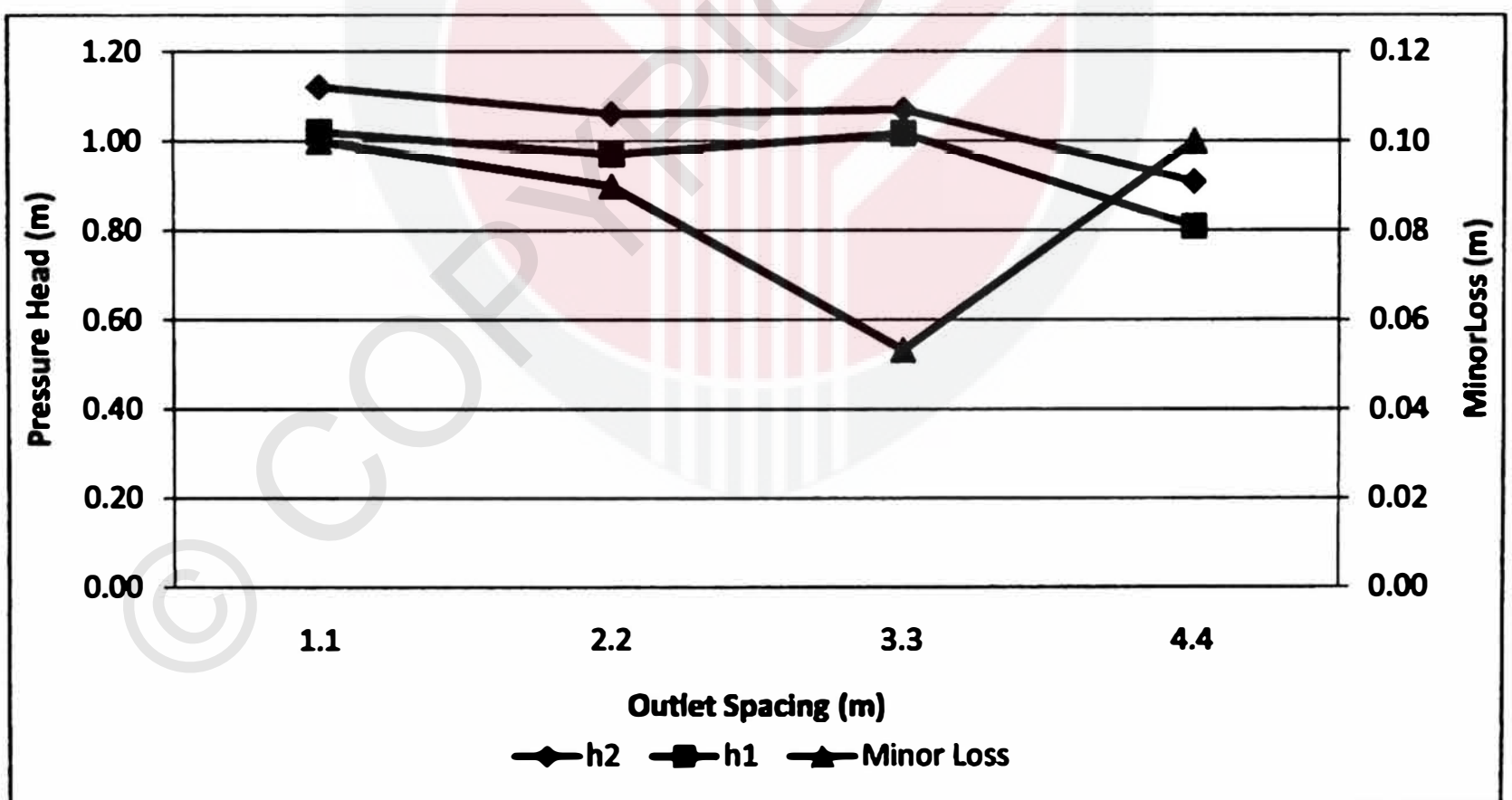
| Main Pipe Diameter (D) |           | Area Ratio (d/D) | Outlet Spacing (m) | Pressure Head (m) |        | Minor Loss (m) |
|------------------------|-----------|------------------|--------------------|-------------------|--------|----------------|
| Inch (")               | Meter (m) |                  |                    | $h_2$             | $h_1$  |                |
| 1.0                    | 0.0254    | 0.50             | 1.1                | 1.1200            | 1.0200 | 0.1000         |
|                        |           |                  | 2.2                | 1.0600            | 0.9700 | 0.0900         |
|                        |           |                  | 3.3                | 1.0700            | 1.0167 | 0.0533         |
|                        |           |                  | 4.4                | 0.9100            | 0.8100 | 0.1000         |
| 1.5                    | 0.0381    | 0.33             | 1.1                | 1.2407            | 1.2350 | 0.0057         |
|                        |           |                  | 2.2                | 1.2613            | 1.2553 | 0.0060         |
|                        |           |                  | 3.3                | 1.2400            | 1.2233 | 0.0167         |
|                        |           |                  | 4.4                | 1.2223            | 1.2100 | 0.0123         |
| 2.0                    | 0.0508    | 0.25             | 1.1                | 1.2663            | 1.2650 | 0.0013         |
|                        |           |                  | 2.2                | 1.2910            | 1.2833 | 0.0077         |
|                        |           |                  | 3.3                | 1.2840            | 1.2800 | 0.0040         |
|                        |           |                  | 4.4                | 1.2707            | 1.2667 | 0.0040         |
| 3.0                    | 0.0762    | 0.17             | 1.1                | 1.2800            | 1.2800 | 0.0000         |
|                        |           |                  | 2.2                | 1.2850            | 1.2850 | 0.0000         |
|                        |           |                  | 3.3                | 1.3100            | 1.3100 | 0.0000         |
|                        |           |                  | 4.4                | 1.2950            | 1.2950 | 0.0000         |

#### 4.1.1 Variation of Pressure Head and Minor Loss at Different Outlet Spacing

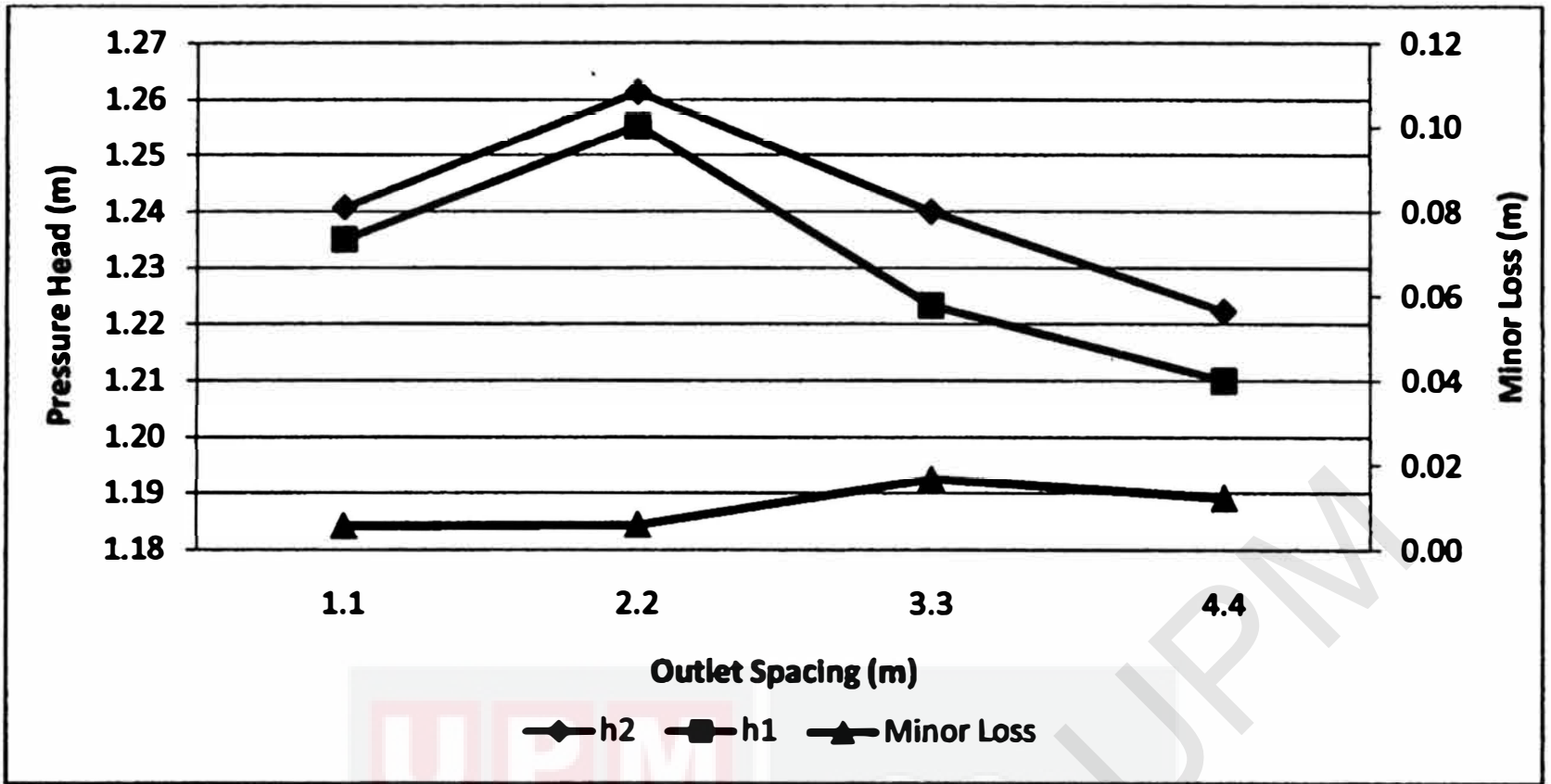
Figure 4.1 to 4.4 shows the variation of pressure head and minor loss along the pipe with the same area ratio but at different outlet spacing varies from 1.1 to 4.4 m. Pressure head in the area ratio pipe of 0.50 decreases with the increases of length of outlet spacing as shown in Figure 4.1. The pressure head at the last outlet before the dead end is minimum due to losses occurred along the multiple outlets pipe. While the minor loss in 0.50 area ratio pipe is maximum with value of 1.0 m at the last outlet before the dead end of the manifold. The pressure head in area ratio pipes 0.33 and 0.25 is the maximum at the second outlet pipe and reduces towards the end of the manifold as shown in

Figure 4.2 and 4.3. Minor loss in area ratio pipe 0.33 is large in the third and last outlet before the end while minor loss in area ratio pipe 0.25 is the highest at the second outlet pipe. The pressure head in area ratio pipe 0.17 is constant before and after the outlets thus there is no loss occurred due to pipe fittings at the outlets. However, the pressure head in 0.17 area ratio pipe increases with the length of outlet spacing and reach the maximum at outlet spacing 3.3 m and reduces at the last outlet before the dead end manifold as shown in Figure 4.4.

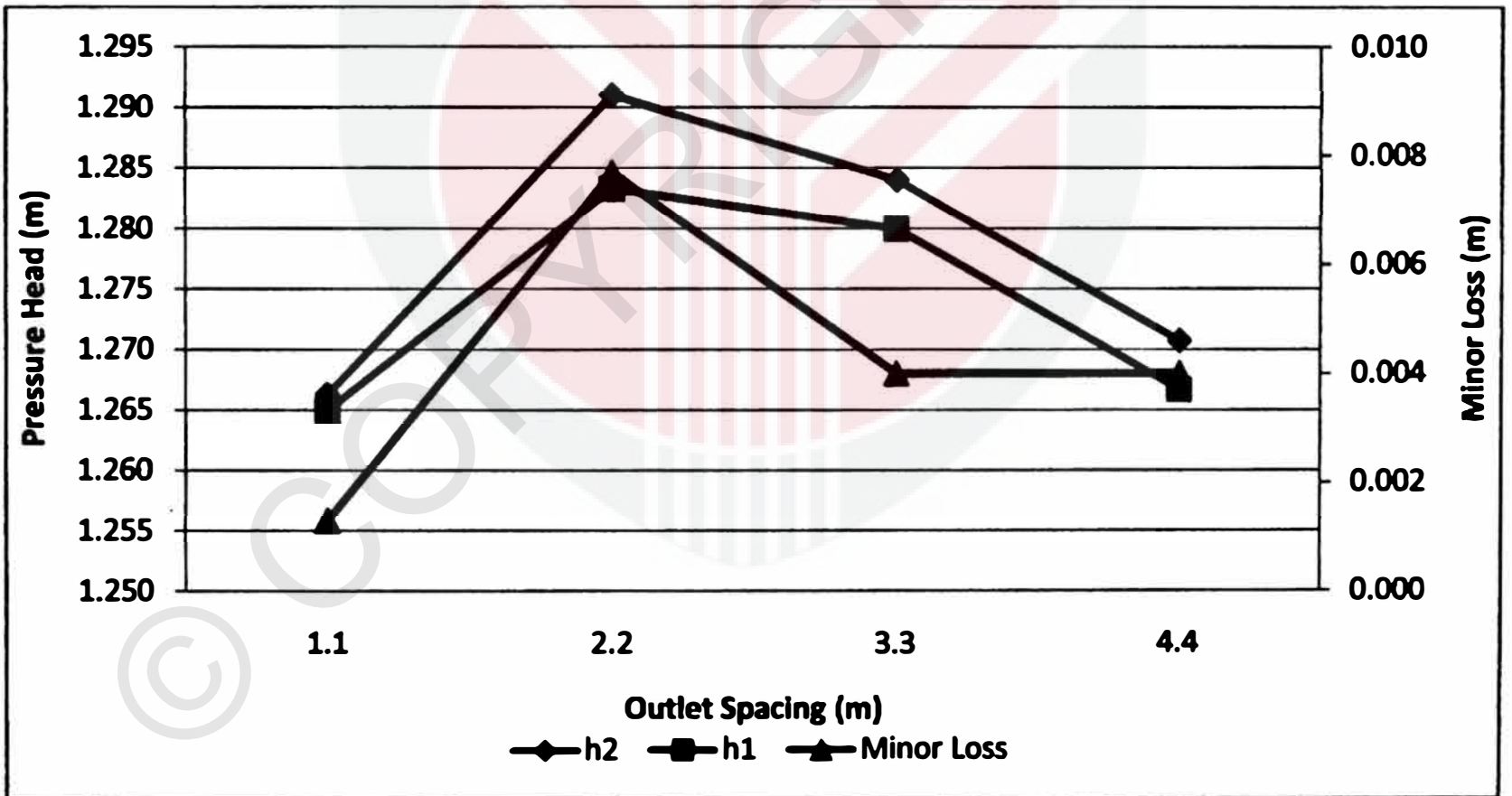
By referring to Figure 4.1 to 4.4, it is found that pressure head decreases along the pipe with various outlets due to energy losses and water discharge in each outlet pipes. The minor loss is increases towards the end of the manifold due to various pipes fitting that produce losses.



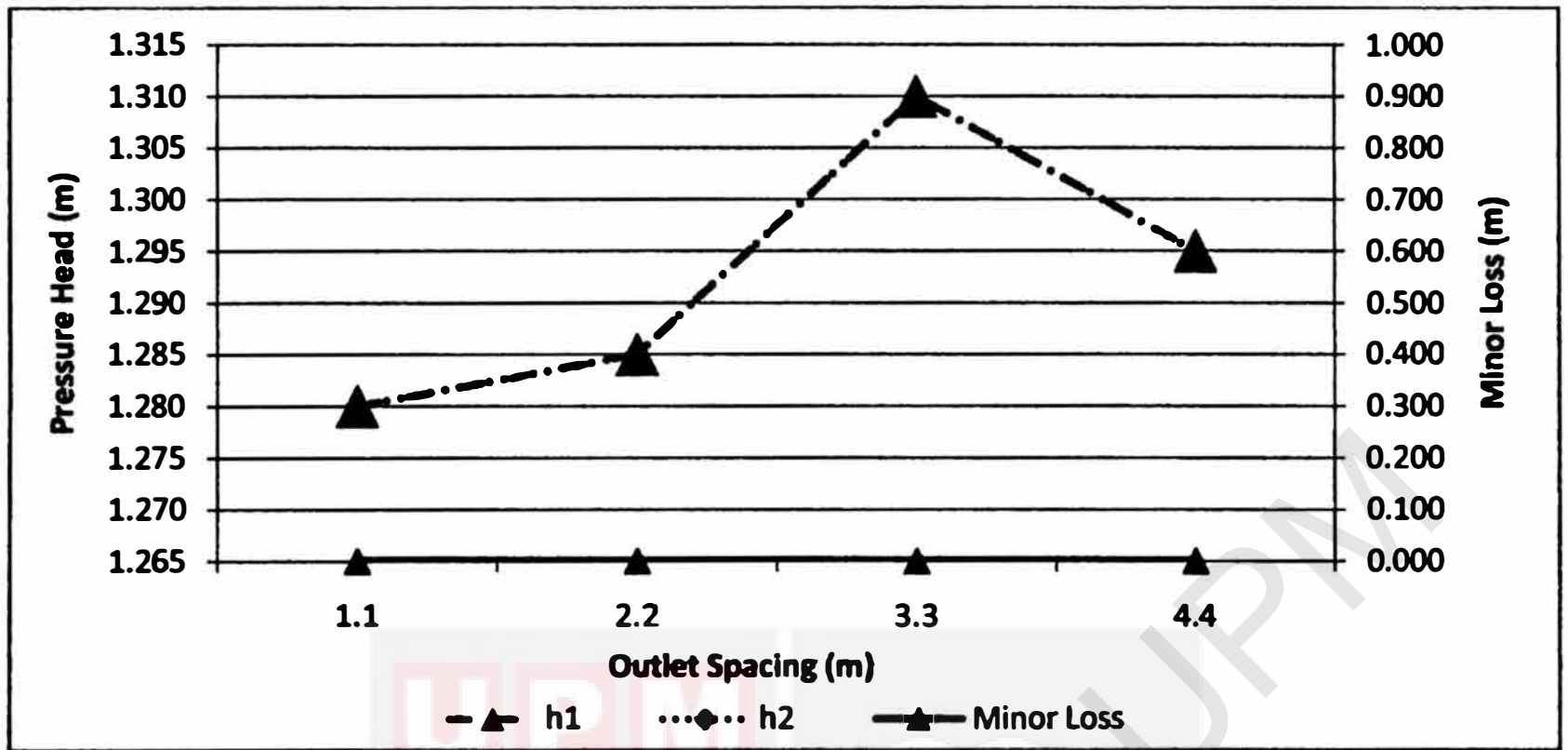
**Figure 4.1: Variation of Pressure Head and Minor Loss with Same Area Ratio at Different Outlet Spacing (AR=0.50)**



**Figure 4.2: Variation of Pressure Head and Minor Loss with Same Area Ratio at Different Outlet Spacing (AR=0.33)**



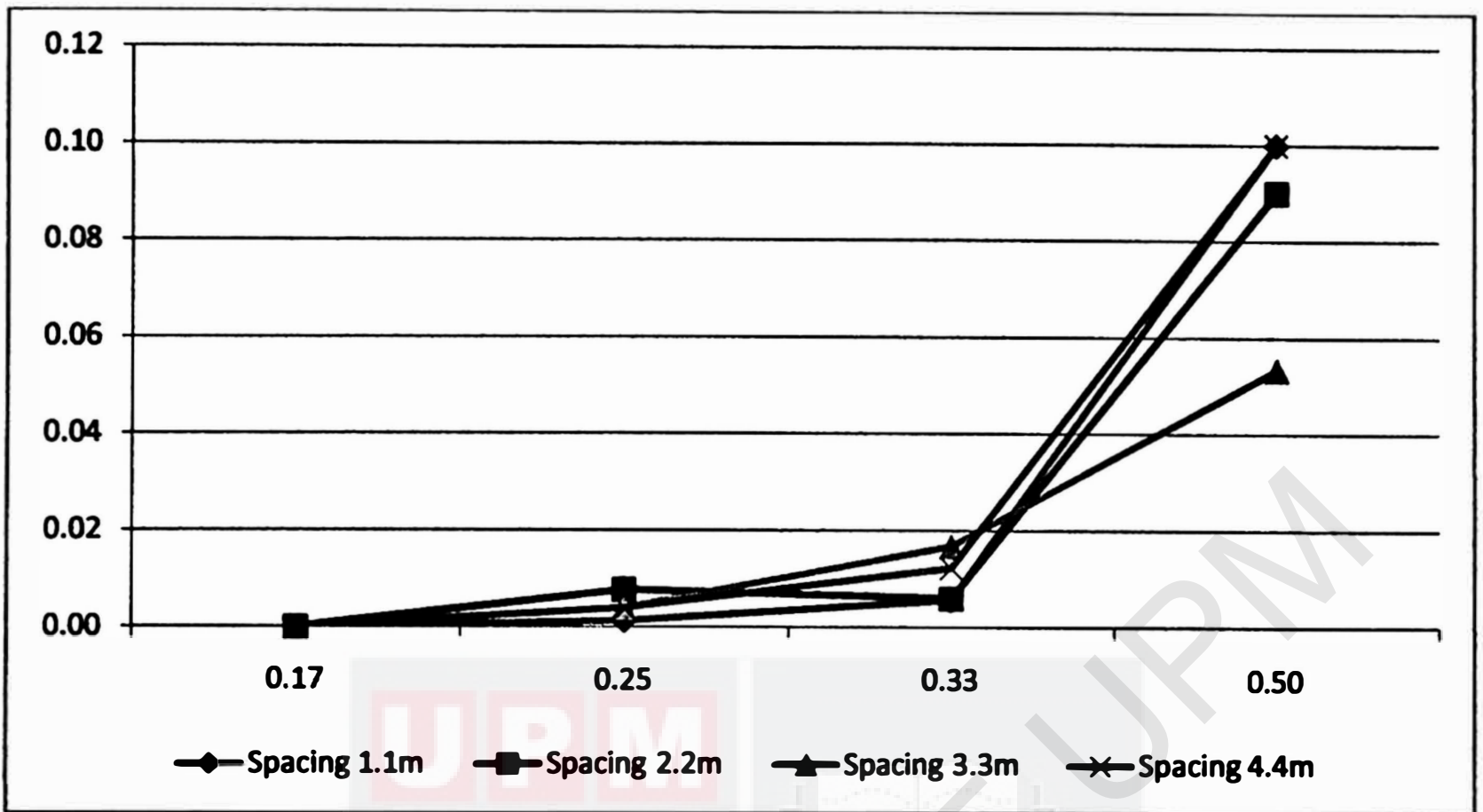
**Figure 4.3: Variation of Pressure Head and Minor Loss with Same Area Ratio at Different Outlet Spacing (AR=0.25)**



**Figure 4.4: Variation of Pressure Head and Minor Loss with Same Area Ratio at Different Outlet Spacing (AR=0.17)**

#### 4.1.2 Variation of Minor Loss with Different Area Ratio Pipe

The variation of minor loss at the same outlet spacing in different area ratio pipe is demonstrated in Figure 4.5. It shows the same trend which the minor loss is the maximum in the biggest area ratio pipe (0.50) at each outlet spacing of 1.1, 2.2, 3.3 and 4.4 m. It is found that the minor loss in a bigger area ratio pipe is higher than smaller area ratio pipe along the manifold. Therefore, based on the data collected, it can be concluded that the smaller area ratio pipe will have smaller minor loss at each outlet along the manifold.



**Figure 4.5: Variation of Minor Loss in Different Area Ratio Pipe at Various Outlet Spacing**

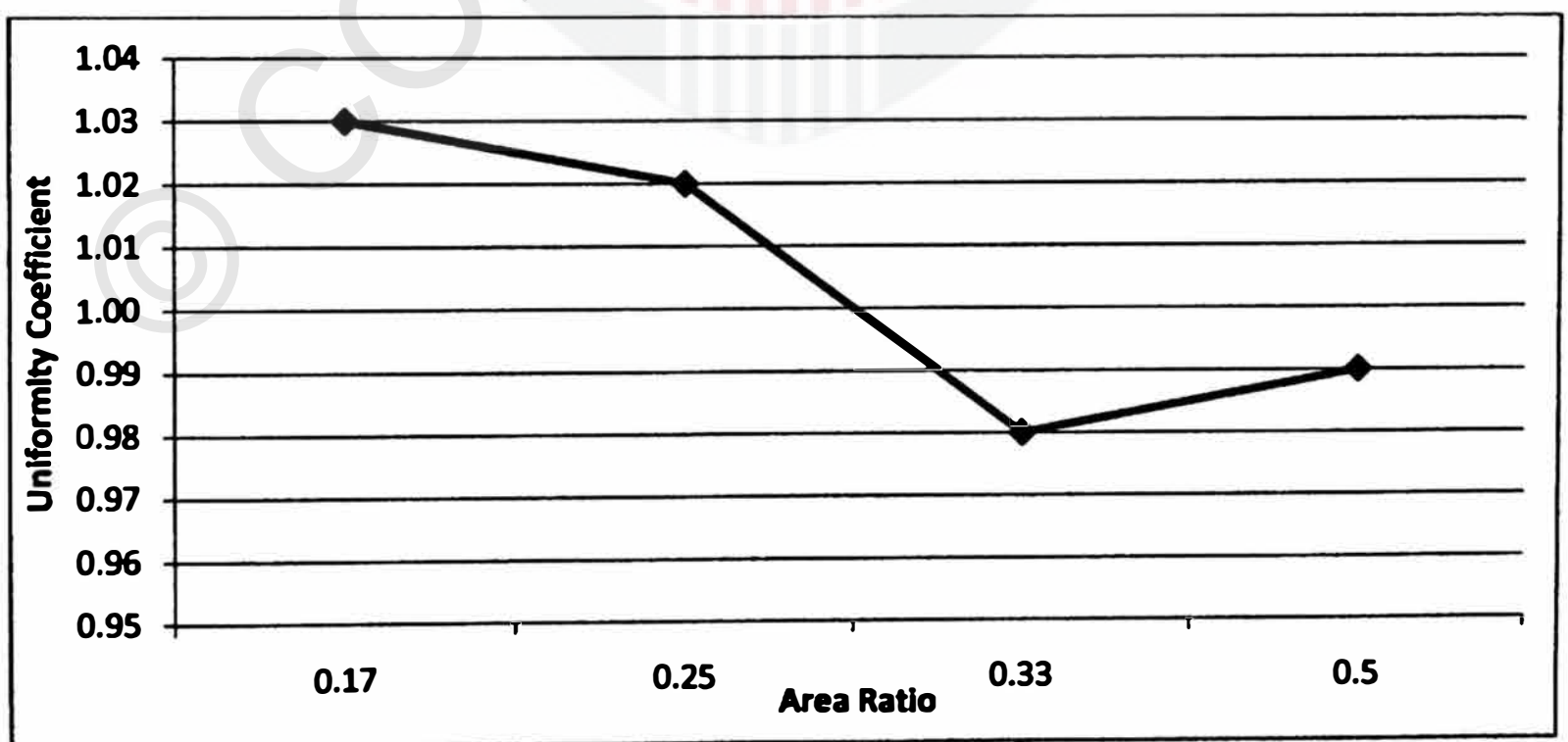
#### **4.2 VARIATION OF UNIFORMITY COEFFICIENT ALONG PVC PIPE WITH DIFFERENT OUTLET SPACING AND AREA RATIO**

Uniformity coefficient illustrates the uniformity of flow distribution in a multiple outlets pipe. Uniformity coefficient is calculated by the ratio of last outlet discharge to first outlet discharge and results are tabulated in Table 4.3. The ideal uniform flow distribution will have equivalent amount of water discharge at the first and last outlets thus produce uniformity coefficient value of 1.0. The variation of uniformity coefficient in different area ratio pipes is as shown in Figure 4.6. The uniformity coefficient varies from 0.99 to 1.03 with the decrement of area ratio pipe. The largest area ratio which is 0.5 produces nearly the most uniform flow distribution compared to other area ratio

pipes. This can be concluded that flow in multiple outlets pipe is nearly uniform for a large area ratio.

**Table 4.3: Discharge and Uniformity Coefficient Data**

| Main Pipe Diameter (D) |           | Area Ratio (d/D) | Outlet Spacing (m) | Discharge (m <sup>3</sup> /s) x10 <sup>-3</sup> | Uniformity Coefficient |
|------------------------|-----------|------------------|--------------------|---|------------------------|
| Inch (")               | Meter (m) |                  |                    |   |                        |
| 1.0                    | 0.0254    | 0.5              | 1.1                | 0.736   | 0.99                   |
|                        |           |                  | 2.2                | 0.721   |                        |
|                        |           |                  | 3.3                | 0.515   |                        |
|                        |           |                  | 4.4                | 0.730   |                        |
| 1.5                    | 0.0381    | 0.33             | 1.1                | 0.814   | 0.98                   |
|                        |           |                  | 2.2                | 0.673   |                        |
|                        |           |                  | 3.3                | 0.791   |                        |
|                        |           |                  | 4.4                | 0.797   |                        |
| 2.0                    | 0.0508    | 0.25             | 1.1                | 0.761   | 1.02                   |
|                        |           |                  | 2.2                | 0.813   |                        |
|                        |           |                  | 3.3                | 0.751   |                        |
|                        |           |                  | 4.4                | 0.781   |                        |
| 3.0                    | 0.0762    | 0.17             | 1.1                | 0.682   | 1.03                   |
|                        |           |                  | 2.2                | 0.704   |                        |
|                        |           |                  | 3.3                | 0.680   |                        |
|                        |           |                  | 4.4                | 0.706   |                        |



**Figure 4.6: Variation of Uniformity Coefficient in Different Area Ratio Pipe**

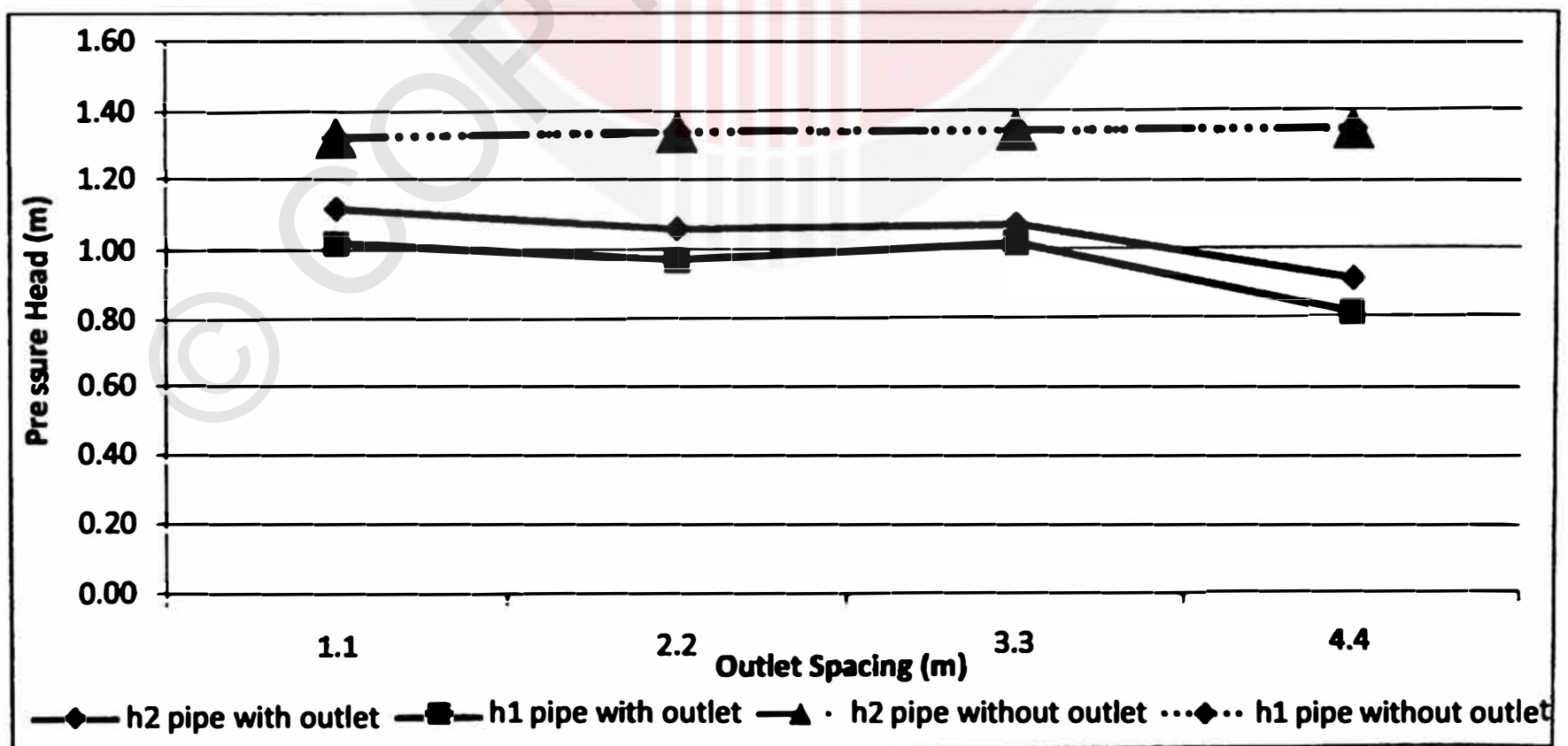
### **4.3 VARIATION OF PRESSURE HEAD IN A MANIFOLD HAVING SAME LENGTH, DIAMETER AND DISCHARGE WITH AND WITHOUT OUTLETS**

The study compares the variation of pressure head in a manifold having same length, diameter and discharge with and without outlets to compare the minor losses between those two pipe conditions as shown in Figure 4.7 to 4.10. The data collected from the study is tabulated in Table 4.4. The pressure head decreases along the pipe having multiple outlets while the pressure head in a pipe without outlets increases towards the end of the pipe. The increasing of pressure head in a pipe without outlets is due to Bernoulli's effect. Bernoulli's theory states that the pressure is inversely proportional to velocity. Velocity decreases along the pipe thus produces higher pressure at the end of the pipe. However, in a pipe having multiple outlets, the pressure head is reduced by each outlet thus produces smaller pressure head at the dead end of the pipe.

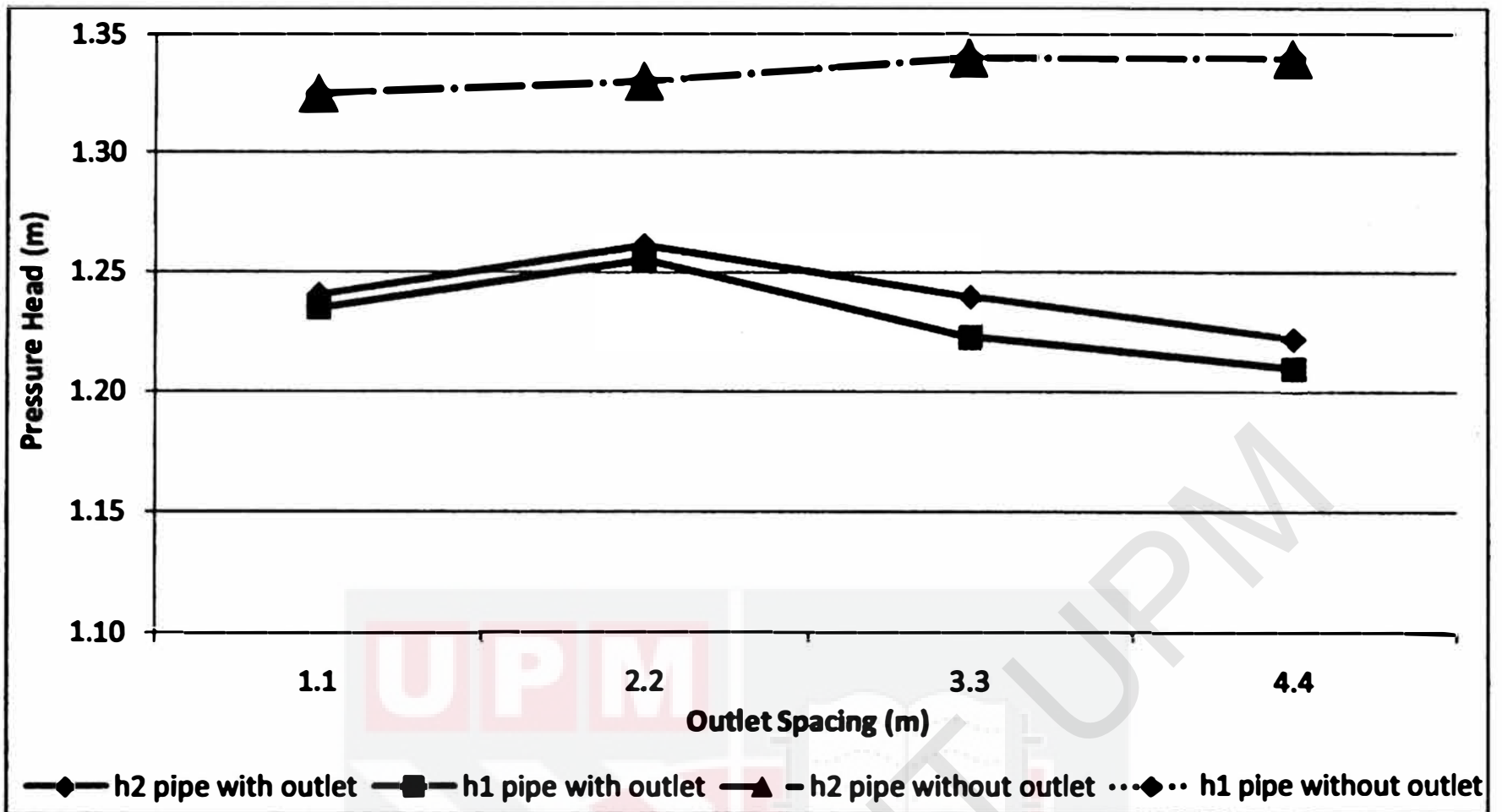
As to compare the minor loss in a pipe with and without outlets, obviously the pipe without outlets does not contribute to any loss due to constant pressure before and after the outlets. This can be explained by no losses occurred from the pipe fittings installed in each outlet of the manifold.

**Table 4.4: Pressure Head in a Manifold with and without Outlets**

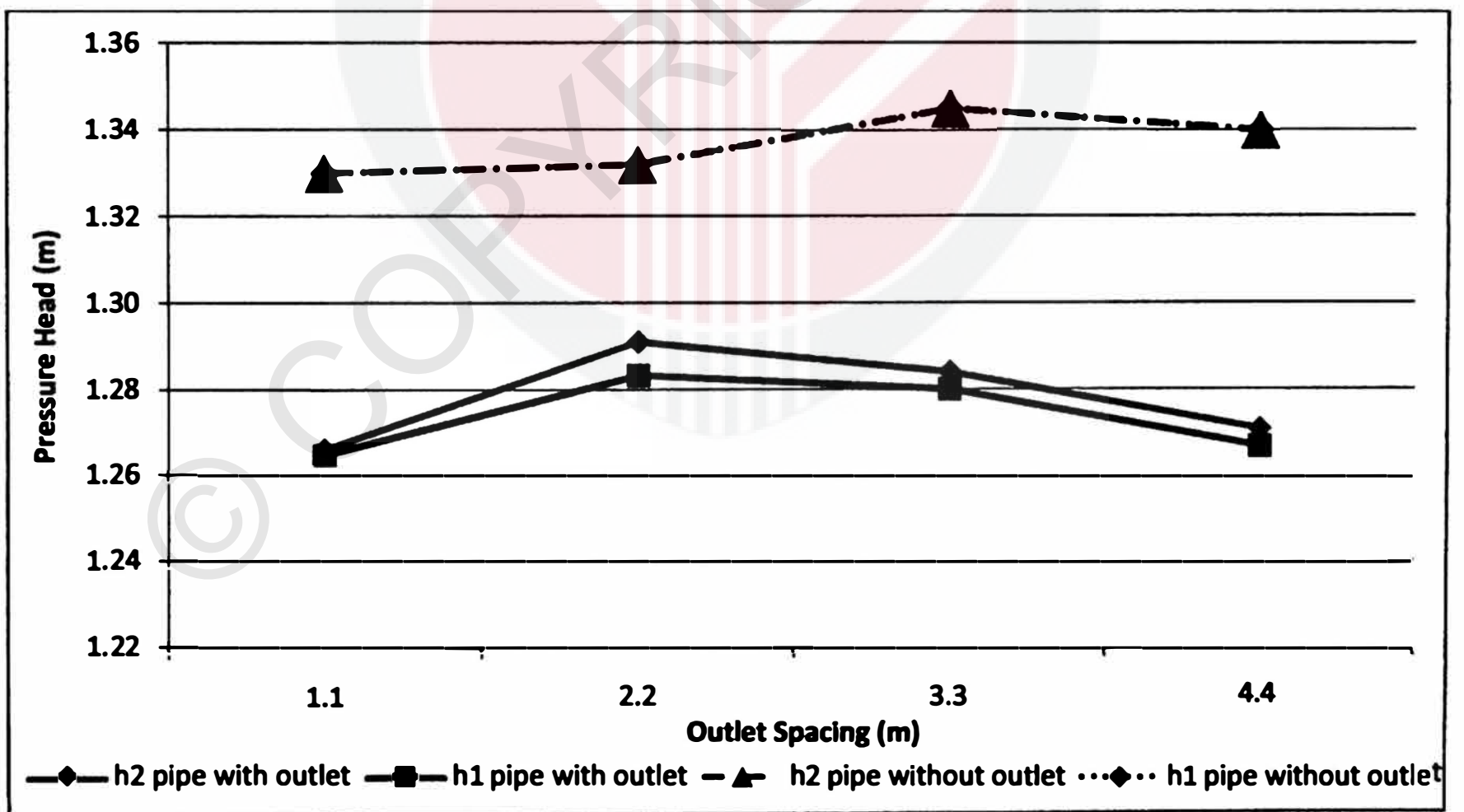
| Main Pipe Diameter (D) |           | Area Ratio (d/D) | Outlet Spacing (m) | h (m)          |                | h <sub>L</sub> (m) | h <sub>close</sub> (m) |                | h <sub>L close</sub> (m) |
|------------------------|-----------|------------------|--------------------|----------------|----------------|--------------------|------------------------|----------------|--------------------------|
| Inch (")               | Meter (m) |                  |                    | h <sub>2</sub> | h <sub>1</sub> |                    | h <sub>2</sub>         | h <sub>1</sub> |                          |
| 1.0                    | 0.0254    | 0.5              | 1.1                | 1.1200         | 1.0200         | 0.1000             | 1.3250                 | 1.3250         | 0.0000                   |
|                        |           |                  | 2.2                | 1.0600         | 0.9700         | 0.0900             | 1.3400                 | 1.3400         | 0.0000                   |
|                        |           |                  | 3.3                | 1.0700         | 1.0167         | 0.0533             | 1.3430                 | 1.3430         | 0.0000                   |
|                        |           |                  | 4.4                | 0.9100         | 0.8100         | 0.1000             | 1.3450                 | 1.3450         | 0.0000                   |
| 1.5                    | 0.0381    | 0.33             | 1.1                | 1.2407         | 1.2350         | 0.0057             | 1.3250                 | 1.3250         | 0.0000                   |
|                        |           |                  | 2.2                | 1.2613         | 1.2553         | 0.0060             | 1.3300                 | 1.3300         | 0.0000                   |
|                        |           |                  | 3.3                | 1.2400         | 1.2233         | 0.0167             | 1.3400                 | 1.3400         | 0.0000                   |
|                        |           |                  | 4.4                | 1.2223         | 1.2100         | 0.0123             | 1.3400                 | 1.3400         | 0.0000                   |
| 2.0                    | 0.0508    | 0.25             | 1.1                | 1.2663         | 1.2650         | 0.0013             | 1.3300                 | 1.3300         | 0.0000                   |
|                        |           |                  | 2.2                | 1.2910         | 1.2833         | 0.0077             | 1.3320                 | 1.3320         | 0.0000                   |
|                        |           |                  | 3.3                | 1.2840         | 1.2800         | 0.0040             | 1.3450                 | 1.3450         | 0.0000                   |
|                        |           |                  | 4.4                | 1.2707         | 1.2667         | 0.0040             | 1.3400                 | 1.3400         | 0.0000                   |
| 3.0                    | 0.0762    | 0.17             | 1.1                | 1.2800         | 1.2800         | 0.0000             | 1.3200                 | 1.3200         | 0.0000                   |
|                        |           |                  | 2.2                | 1.2850         | 1.2850         | 0.0000             | 1.3300                 | 1.3300         | 0.0000                   |
|                        |           |                  | 3.3                | 1.3100         | 1.3100         | 0.0000             | 1.3300                 | 1.3300         | 0.0000                   |
|                        |           |                  | 4.4                | 1.2950         | 1.2950         | 0.0000             | 1.3350                 | 1.3350         | 0.0000                   |



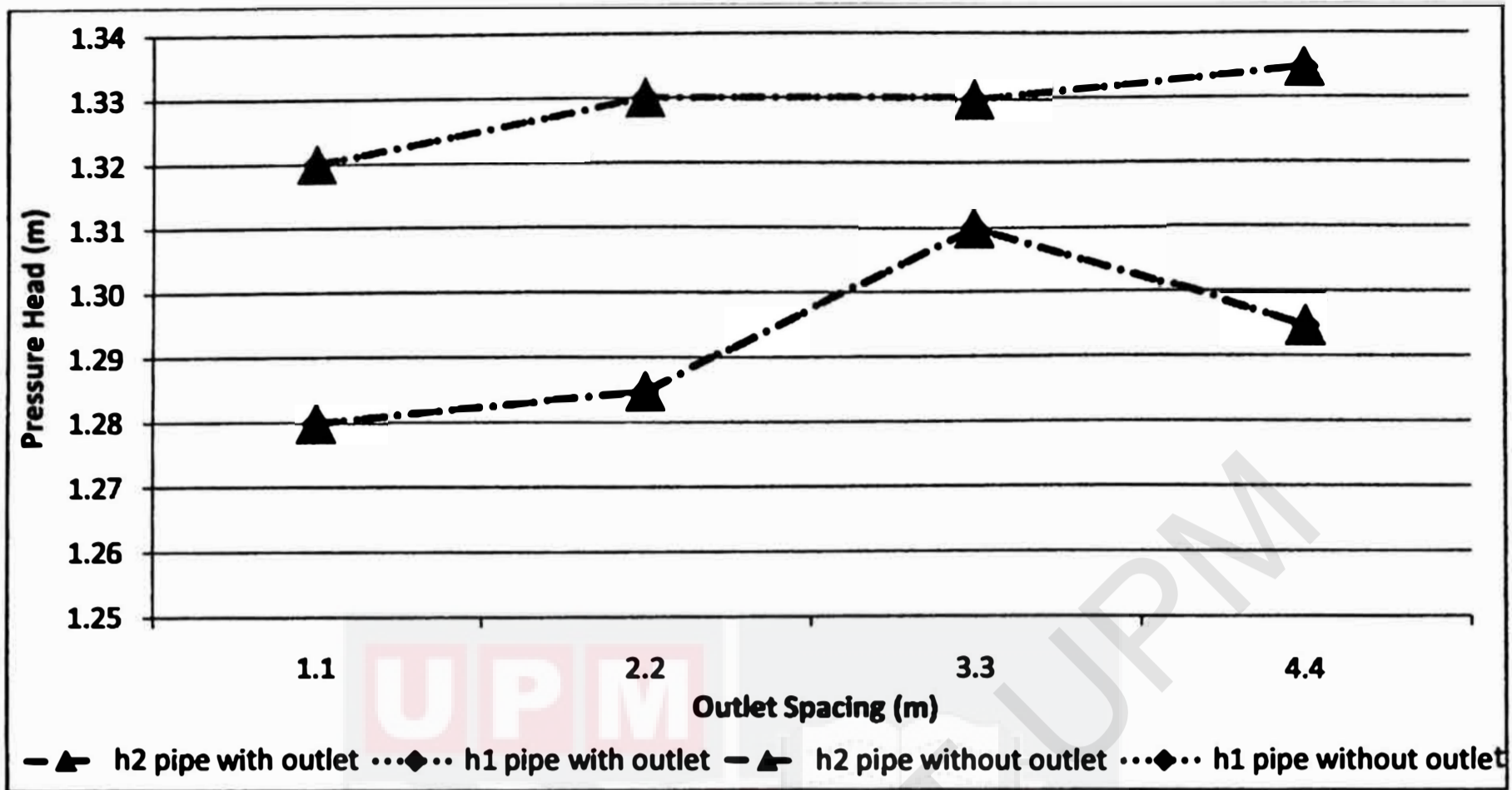
**Figure 4.7: Comparison of Pressure Head in the Same Pipe with and without Outlet (AR = 0.50)**



**Figure 4.8: Comparison of Pressure Head in the Same Pipe with and without Outlet (AR = 0.33)**



**Figure 4.9: Comparison of Pressure Head in the Same Pipe with and Without Outlet (AR = 0.25)**



**Figure 4.10: Comparison of Pressure Head in the Same Pipe with and Without Outlet (AR = 0.17)**

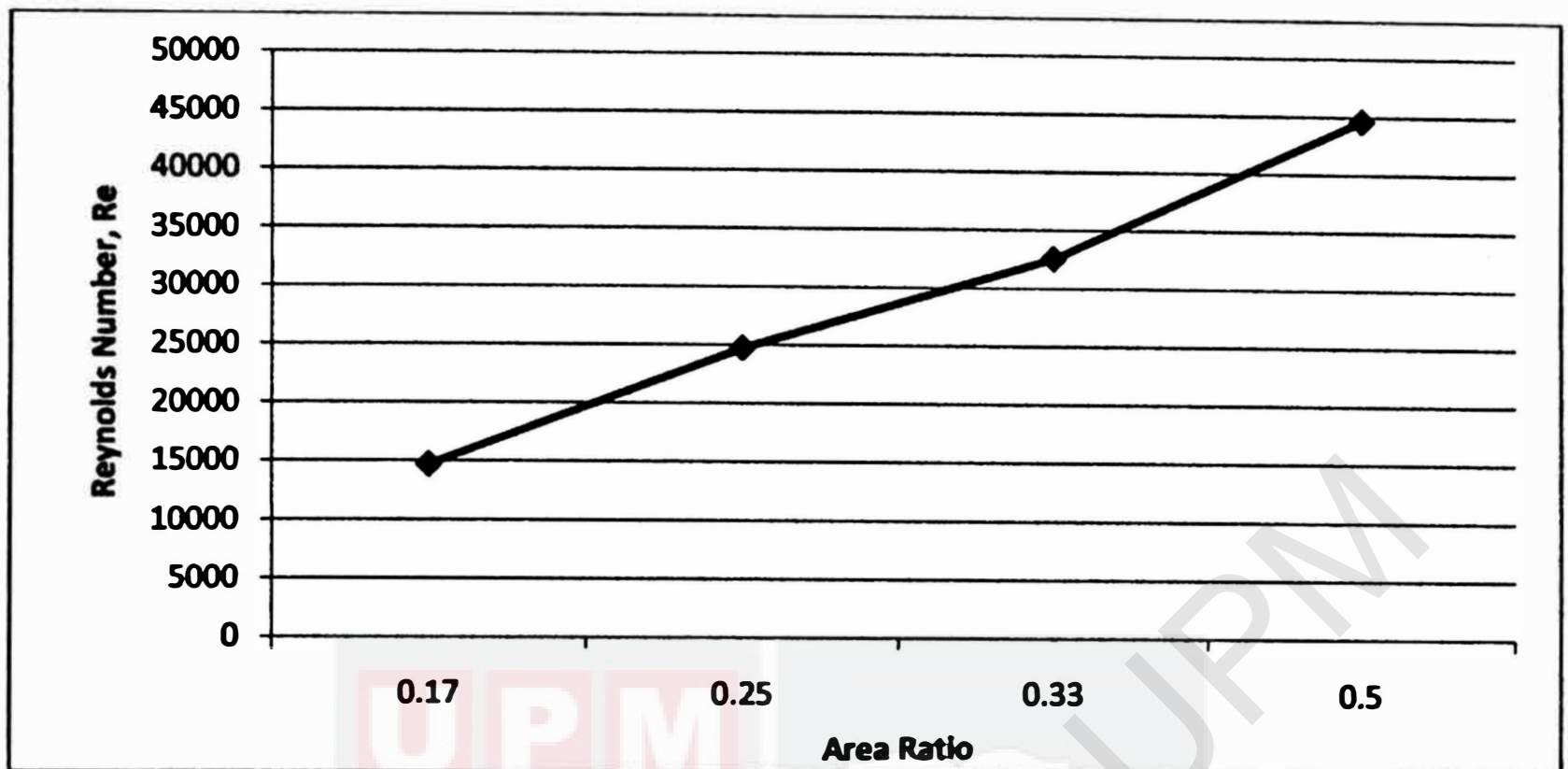
#### **4.4 VARIATION OF RESISTANCE COEFFICIENT, K OF A MULTIPLE OUTLETS PIPE WITH VARIOUS SPACING AND AREA RATIO AND COMPARED WITH THEORETICAL K VALUE**

Resistance coefficient,  $k$  is varied depending on the different type of piping components along the manifold. However, the  $k$  values considered in this study are only due to pipe fitting which is installed at the outlet pipes. Experimental  $k$  is calculated using equation 2.12 while equation 2.13 is used to calculate the theoretical  $k$ . According to the theory, this equation only valid if the flow is in a complete turbulence. Thus, the Reynolds number,  $Re$  from the study is first calculated for different outlet spacing and the average  $Re$  is then obtained.  $Re$  is obtained from the experiment is tabulated in Table 4.5 and represented in Figure 4.11. In all cases,  $Re$  values greater than 4000 thus verify that the

flow is in complete turbulence. Although the value of Re is not constant along the manifold and decreases towards the end, but the average flow of the manifold can be considered as complete turbulence. Re is increases with the increment of area ratio as shown in Figure 4.11.

**Table 4.5: Reynolds Number Data**

| Main Pipe Diameter (D) |           | Area Ratio (d/D) | Outlet Spacing (m) | Velocity, v (m/s) | Kinematic Viscosity (m <sup>2</sup> /s) x 10 <sup>-6</sup> | Re    | Average Re |
|------------------------|-----------|------------------|--------------------|-------------------|--|-------|------------|
| Inch (")               | Meter (m) |                  |                    |                   |  |       |            |
| 1.0                    | 0.0254    | 0.5              | 1.1                | 1.4510            | 0.7851   | 48615 | 44634      |
|                        |           |                  | 2.2                | 1.4221            |  | 47647 |            |
|                        |           |                  | 3.3                | 1.0158            |  | 34034 |            |
|                        |           |                  | 4.4                | 1.4398            |  | 48240 |            |
| 1.5                    | 0.0381    | 0.33             | 1.1                | 0.7143            | 0.7867   | 34593 | 32565      |
|                        |           |                  | 2.2                | 0.5901            |  | 28578 |            |
|                        |           |                  | 3.3                | 0.6939            |  | 33605 |            |
|                        |           |                  | 4.4                | 0.6988            |  | 33842 |            |
| 2.0                    | 0.0508    | 0.25             | 1.1                | 0.3754            | 0.7867   | 24241 | 24738      |
|                        |           |                  | 2.2                | 0.4012            |  | 25907 |            |
|                        |           |                  | 3.3                | 0.3705            |  | 23924 |            |
|                        |           |                  | 4.4                | 0.3853            |  | 24880 |            |
| 3.0                    | 0.0762    | 0.17             | 1.1                | 0.1496            | 0.7867   | 14490 | 14723      |
|                        |           |                  | 2.2                | 0.1545            |  | 14965 |            |
|                        |           |                  | 3.3                | 0.1491            |  | 14442 |            |
|                        |           |                  | 4.4                | 0.1548            |  | 14994 |            |

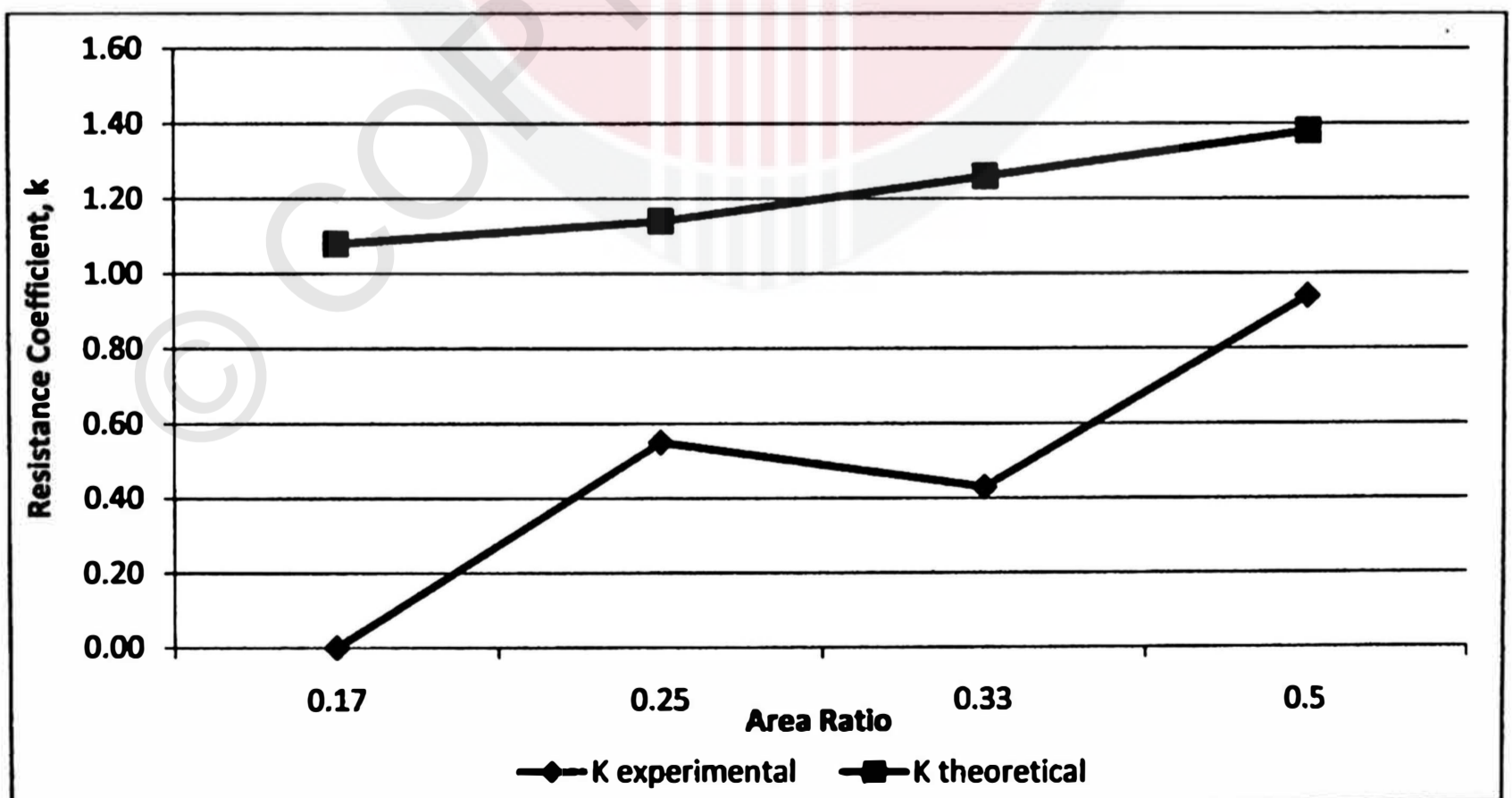


**Figure 4.11: Variation of Reynolds Number in Different Area Ratio Manifold**

After the state of flow is determined and verified as complete turbulence, the theoretical  $k$  is calculated using equation 2.13 and tabulated in Table 4.6. The comparison of theoretical and experimental  $k$  value along the manifold is shown in Figure 4.12 where  $k$  increases with the increment of area ratio. However, there are quite significant differences in experimental and theoretical  $k$  values. One possible reason is that, the resistance coefficient in a pipe varies from many types of valves and fittings, thus the conclusion is made whereby the different values of experimental and theoretical  $k$  are observed may probably be due to other piping components in the pipe not being taken into consideration in this study.

**Table 4.6: Resistance Coefficient, k from Experiment and Theoretical**

| Main Pipe Diameter (D) |           | Area Ratio (d/D) | Outlet Spacing (m) | Head Loss (m) | $k_{\text{experimental}}$ | Average $k_{\text{experimental}}$ | $k_{\text{theoretical}}$ |
|------------------------|-----------|------------------|--------------------|---------------|---------------------------|-----------------------------------|--------------------------|
| Inch (")               | Meter (m) |                  |                    |               |                           |                                   |                          |
| 1.0                    | 0.0254    | 0.5              | 1.1                | 0.1000        | 0.9319                    | 0.94                              | 1.38                     |
|                        |           |                  | 2.2                | 0.0900        | 0.8731                    |                                   |                          |
|                        |           |                  | 3.3                | 0.0533        | 1.0135                    |                                   |                          |
|                        |           |                  | 4.4                | 0.1000        | 0.9464                    |                                   |                          |
| 1.5                    | 0.0381    | 0.33             | 1.1                | 0.0057        | 0.2192                    | 0.43                              | 1.26                     |
|                        |           |                  | 2.2                | 0.0060        | 0.3381                    |                                   |                          |
|                        |           |                  | 3.3                | 0.0167        | 0.6805                    |                                   |                          |
|                        |           |                  | 4.4                | 0.0123        | 0.4942                    |                                   |                          |
| 2.0                    | 0.0508    | 0.25             | 1.1                | 0.0013        | 0.1810                    | 0.55                              | 1.14                     |
|                        |           |                  | 2.2                | 0.0077        | 0.9386                    |                                   |                          |
|                        |           |                  | 3.3                | 0.0040        | 0.5717                    |                                   |                          |
|                        |           |                  | 4.4                | 0.0040        | 0.5286                    |                                   |                          |
| 3.0                    | 0.0762    | 0.17             | 1.1                | 0.0000        | 0.0000                    | 0.00                              | 1.08                     |
|                        |           |                  | 2.2                | 0.0000        | 0.0000                    |                                   |                          |
|                        |           |                  | 3.3                | 0.0000        | 0.0000                    |                                   |                          |
|                        |           |                  | 4.4                | 0.0000        | 0.0000                    |                                   |                          |



**Figure 4.12: Comparison of Resistance Coefficient  $k_{\text{experimental}}$  and  $k_{\text{theoretical}}$**

## **CHAPTER FIVE**

### **CONCLUSIONS AND RECOMMENDATIONS**

#### **5.1 CONCLUSIONS**

A physical model of a multiple outlets pipe is designed, fabricated and tested to assess the discharge uniformity along the pipe and minor losses at each pipe outlet. The lateral pipe diameter is constant in each manifold which is 0.0127 m (1/2") with the main pipe diameter varies from 0.0127 m (1/2") to 0.0762 m (3"). However, during the experiments, the water supply was insufficient to reach to the end of the manifold in main pipe diameter of 0.0127 m. Due to this reason, analysis is mainly discussed on the main pipe diameter varies from 0.0254 m (1") to 0.0762 m (3") and area ratio considered are 0.17, 0.25, 0.33 and 0.5. The outlet spacing is varies from 1.1 m to 4.4 m and equally spaced between each outlet. The experiment is carried out by using constant head of 1.70 m that is achieved when the water in the water tank flow out from the tank into the overflow pipe. The data of pressure head, discharge and water temperature are recorded and analyzed.

From the result obtained, it is found that pipe fitting and area ratio are the factors that affect the variation of minor loss. Experimental results show that the pressure head in a pipe with various outlets decreases towards the dead end of the manifold. While for a pipe without outlets, the pressure head increases towards the dead end of the manifold

that is explained by Bernoulli's effects. Bernoulli's theory states that the pressure is inversely proportional to velocity. Velocity decreases along the pipe without outlets thus produce higher pressure at the end of the pipe. By comparing the pipe having the same length, diameter and discharge between cases with and without outlets, the trend shows that the pressure head in pipe with outlets decreases with outlet spacing while the pressure head in pipe without outlets increases towards the end of the manifold. The minor loss is calculated from the difference in pressure head before and after the outlets. Pipe with outlets exhibits the minor loss along the pipe and the losses increasing towards the last outlet before the dead end of the manifold. On the other hand, pipe without outlets does not have any head loss along the pipe due to constant pressure before and after each outlet.

The uniformity of the flow is analyzed using the discharge from each outlet. A flow is considered uniform if the water discharge from the last outlet of the pipe is approximately the same as the first outlet discharge which give the value of uniformity of 1.0. From the experiment, the most uniform flow is in the bigger area ratio (0.50) which is due to fewer disturbances in the water path resulting from the deviation in diameter of lateral and main pipe diameter. Resistance coefficient,  $k$  is calculated from both theoretical and experimental. The theoretical equation used to calculate  $k$  is based on each piping component that results in energy loss including entrance, exit, sudden enlargement, sudden contraction, valves, fitting. However, the real piping system consists of several types of piping components that may contribute to energy losses. This study limits the consideration of energy loss due to pipe fittings from the outlet pipes only thus deviation between the value of  $k$  theoretical and experimental is

prevailed. Further study by considering various piping components is required to obtain more accurate results.

## **5.2 RECOMMENDATIONS**

Although this study has achieved the objectives, there are some recommendations that might be useful for further study. These recommendations are useful to improve the current work and for extended it to make it more comprehensive.

This study proves that the minor loss in a multiple outlets pipe is generally increasing with increases of area ratio pipe. To complete the whole relationship, it is required to study the ranges that are not covered in this study by using more various main pipe diameters. The variation in main pipe diameter will produce various area ratio pipe and given various results to be compared. Other than that, the existing water tank at hydraulic laboratory needs to be replaced with the new water tank because there is leakage that can disturbs the results obtained from the experiment. The leakage can cause the water head is not constant and affects the uniformity of the flow. Elevating the height of water tank is useful to increase the inflow pressure inside the manifold so that the sufficient water pressure can be distributed until the end of the manifold. Last but not least, as this study only focuses on one pipe fitting installed in the outlets pipe, the value of  $k$  is not as expected. It is better to consider the variation of  $k$  due to various piping components in a manifold thus may improve the comparison of theoretical and experimental  $k$  value.

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## **APPENDICES**

**APPENDIX A      RAW DATA OBTAINED FROM EXPERIMENT**

**APPENDIX B      RESULTS AND CALCULATIONS**

**APPENDIX C      SAMPLE CALCULATION**



**APPENDIX A**

**RAW DATA OBTAINED FROM EXPERIMENT**

**Appendix A1: Raw Data for 0.5” Pipe**

| Diameter |           | Area Ratio | Outlet Spacing (m) | Volume (L) |       |       |         | h (cm)         |                |                |                |                |                |                |                | h <sub>close</sub> (cm) |                |
|----------|-----------|------------|--------------------|------------|-------|-------|---------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-------------------------|----------------|
| Inch (") | Meter (m) |            |                    | 1          | 2     | 3     | Average | 1              |                | 2              |                | 3              |                | Average        |                | h <sub>2</sub>          | h <sub>1</sub> |
|          |           |            |                    |            |       |       |         | h <sub>2</sub> | h <sub>1</sub> | h <sub>2</sub> | h <sub>1</sub> | h <sub>2</sub> | h <sub>1</sub> | h <sub>2</sub> | h <sub>1</sub> |                         |                |
| 0.5      | 0.0127    | 1.00       | 1.1                | 17.00      | 16.90 | 17.00 | 16.97   | 36.00          | 2.00           | 30.00          | 2.00           | 30.00          | 2.00           | 32.00          | 2.00           | 131.0                   | 131.0          |
|          |           |            | 2.2                | 15.60      | 15.60 | 15.60 | 15.60   | 19.00          | -              | 19.00          | -              | 19.00          | -              | 19.00          | -              | 132.0                   | 132.0          |
|          |           |            | 3.3                | 14.00      | 13.90 | 14.20 | 14.03   | 6.00           | -              | 6.00           | -              | 6.00           | -              | 6.00           | -              | 133.0                   | 133.0          |
|          |           |            | 4.4                | 12.60      | 12.50 | 12.60 | 12.57   | 2.00           | -              | 2.00           | -              | 2.00           | -              | 2.00           | -              | 133.8                   | 133.8          |

**Appendix A2: Raw Data for 1.0” Pipe**

| Diameter |           | Area Ratio | Outlet Spacing (m) | Volume (L) |       |       |         | h (cm)         |                |                |                |                |                |                |                | h <sub>close</sub> (cm) |                |
|----------|-----------|------------|--------------------|------------|-------|-------|---------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-------------------------|----------------|
| Inch (") | Meter (m) |            |                    | 1          | 2     | 3     | Average | 1              |                | 2              |                | 3              |                | Average        |                | h <sub>2</sub>          | h <sub>1</sub> |
|          |           |            |                    |            |       |       |         | h <sub>2</sub> | h <sub>1</sub> | h <sub>2</sub> | h <sub>1</sub> | h <sub>2</sub> | h <sub>1</sub> | h <sub>2</sub> | h <sub>1</sub> |                         |                |
| 1.0      | 0.0254    | 0.5        | 1.1                | 22.20      | 22.10 | 21.90 | 22.07   | 112.00         | 102.00         | 112.00         | 102.00         | 112.00         | 102.00         | 112.00         | 102.00         | 132.5                   | 132.5          |
|          |           |            | 2.2                | 21.60      | 21.60 | 21.70 | 21.63   | 106.00         | 97.00          | 106.00         | 97.00          | 106.00         | 97.00          | 106.00         | 97.00          | 134.0                   | 134.0          |
|          |           |            | 3.3                | 18.75      | 18.80 | 18.80 | 18.78   | 107.00         | 102.00         | 107.00         | 101.50         | 107.00         | 101.50         | 107.00         | 101.67         | 134.3                   | 134.3          |
|          |           |            | 4.4                | 22.10      | 21.80 | 21.80 | 21.90   | 91.00          | 81.00          | 91.00          | 81.00          | 91.00          | 81.00          | 91.00          | 81.00          | 134.5                   | 134.5          |

### Appendix A3: Raw Data for 1.5" Pipe

| Diameter    |              | Area<br>Ratio | Outlet<br>Spacing<br>(m) | Volume (L) |       |       |         | h (cm)         |                |                |                |                |                |                |                | h <sub>close</sub> (cm) |                |
|-------------|--------------|---------------|--------------------------|------------|-------|-------|---------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-------------------------|----------------|
| Inch<br>(") | Meter<br>(m) |               |                          | 1          | 2     | 3     | Average | 1              |                | 2              |                | 3              |                | Average        |                | h <sub>2</sub>          | h <sub>1</sub> |
|             |              |               |                          |            |       |       |         | h <sub>2</sub> | h <sub>1</sub> | h <sub>2</sub> | h <sub>1</sub> | h <sub>2</sub> | h <sub>1</sub> | h <sub>2</sub> | h <sub>1</sub> |                         |                |
| 1.5         | 0.0381       | 0.33          | 1.1                      | 24.40      | 24.40 | 24.50 | 24.43   | 124.00         | 123.50         | 124.20         | 123.50         | 124.00         | 123.50         | 124.07         | 123.50         | 132.5                   | 132.5          |
|             |              |               | 2.2                      | 19.95      | 20.30 | 20.30 | 20.18   | 126.00         | 125.50         | 126.20         | 125.50         | 126.20         | 125.60         | 126.13         | 125.53         | 133.0                   | 133.0          |
|             |              |               | 3.3                      | 23.70      | 23.70 | 23.80 | 23.73   | 125.00         | 122.50         | 123.50         | 122.50         | 123.50         | 122.00         | 124.00         | 122.33         | 134.0                   | 134.0          |
|             |              |               | 4.4                      | 24.10      | 23.80 | 23.80 | 23.90   | 122.00         | 121.00         | 122.50         | 121.00         | 122.20         | 121.00         | 122.23         | 121.00         | 134.0                   | 134.0          |

### Appendix A4: Raw Data for 2.0" Pipe

| Diameter    |              | Area<br>Ratio | Outlet<br>Spacing<br>(m) | Volume (L) |       |       |         | h (cm)         |                |                |                |                |                |                |                | h <sub>close</sub> (cm) |                |
|-------------|--------------|---------------|--------------------------|------------|-------|-------|---------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-------------------------|----------------|
| Inch<br>(") | Meter<br>(m) |               |                          | 1          | 2     | 3     | Average | 1              |                | 2              |                | 3              |                | Average        |                | h <sub>2</sub>          | h <sub>1</sub> |
|             |              |               |                          |            |       |       |         | h <sub>2</sub> | h <sub>1</sub> | h <sub>2</sub> | h <sub>1</sub> | h <sub>2</sub> | h <sub>1</sub> | h <sub>2</sub> | h <sub>1</sub> |                         |                |
| 2.0         | 0.0508       | 0.25          | 1.1                      | 22.90      | 22.90 | 22.70 | 22.83   | 126.70         | 126.50         | 126.70         | 126.50         | 126.50         | 126.50         | 126.63         | 126.50         | 133.0                   | 133.0          |
|             |              |               | 2.2                      | 24.30      | 24.40 | 24.50 | 24.40   | 129.10         | 128.00         | 129.10         | 129.00         | 129.10         | 128.00         | 129.10         | 128.33         | 133.2                   | 133.2          |
|             |              |               | 3.3                      | 22.40      | 22.60 | 22.60 | 22.53   | 128.00         | 127.50         | 128.50         | 128.00         | 128.70         | 128.50         | 128.40         | 128.00         | 134.5                   | 134.5          |
|             |              |               | 4.4                      | 23.60      | 23.10 | 23.60 | 23.43   | 127.50         | 127.00         | 127.00         | 126.50         | 126.70         | 126.50         | 127.07         | 126.67         | 134.0                   | 134.0          |

**Appendix A5: Raw Data for 3.0" Pipe**

| Diameter    |              | Area  | Outlet         | Volume (L) |       |       |         | h (cm)         |                |                |                |                |                |                |                | h <sub>close</sub> (cm) |                |
|-------------|--------------|-------|----------------|------------|-------|-------|---------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-------------------------|----------------|
| Inch<br>(") | Meter<br>(m) | Ratio | Spacing<br>(m) | 1          | 2     | 3     | Average | 1              |                | 2              |                | 3              |                | Average        |                | h <sub>2</sub>          | h <sub>1</sub> |
|             |              |       |                |            |       |       |         | h <sub>2</sub> | h <sub>1</sub> | h <sub>2</sub> | h <sub>1</sub> | h <sub>2</sub> | h <sub>1</sub> | h <sub>2</sub> | h <sub>1</sub> |                         |                |
| 3.0         | 0.0762       | 0.17  | 1.1            | 20.50      | 20.40 | 20.50 | 20.47   | 128.00         | 128.00         | 128.00         | 128.00         | 128.00         | 128.00         | 128.00         | 128.00         | 132.0                   | 132.0          |
|             |              |       | 2.2            | 21.20      | 21.00 | 21.20 | 21.13   | 128.50         | 128.50         | 128.50         | 128.50         | 128.50         | 128.50         | 128.50         | 128.50         | 133.0                   | 133.0          |
|             |              |       | 3.3            | 20.40      | 20.40 | 20.40 | 20.40   | 131.00         | 131.00         | 131.00         | 131.00         | 131.00         | 131.00         | 131.00         | 131.00         | 133.0                   | 133.0          |
|             |              |       | 4.4            | 21.10      | 21.10 | 21.30 | 21.17   | 129.50         | 129.50         | 129.50         | 129.50         | 129.50         | 129.50         | 129.50         | 129.50         | 133.5                   | 133.5          |

### Appendix A6: Temperature Reading

| Pipe Area Ratio | Water Level (m) | Spacing (m) | Temperature (°C) | Kinematic Viscosity (m <sup>2</sup> /s) x 10 <sup>-6</sup> |
|-----------------|-----------------|-------------|------------------|--|
| 1.00            | 1.7             | 1.1         | 31               | 0.7867   |
|                 |                 | 2.2         |                  |  |
|                 |                 | 3.3         |                  |  |
|                 |                 | 4.4         |                  |  |
| 0.50            | 1.7             | 1.1         | 33               | 0.7581   |
|                 |                 | 2.2         |                  |  |
|                 |                 | 3.3         |                  |  |
|                 |                 | 4.4         |                  |  |
| 0.33            | 1.7             | 1.1         | 31               | 0.7867   |
|                 |                 | 2.2         |                  |  |
|                 |                 | 3.3         |                  |  |
|                 |                 | 4.4         |                  |  |
| 0.25            | 1.7             | 1.1         | 31               | 0.7867   |
|                 |                 | 2.2         |                  |  |
|                 |                 | 3.3         |                  |  |
|                 |                 | 4.4         |                  |  |
| 0.17            | 1.7             | 1.1         | 31               | 0.7867   |
|                 |                 | 2.2         |                  |  |
|                 |                 | 3.3         |                  |  |
|                 |                 | 4.4         |                  |  |

**APPENDIX B**

**CALCULATED RESULTS**

**Appendix B1: Calculated Data for 0.5” Pipe**

| Diameter    |              | Main Pipe Area<br>(m <sup>2</sup> ) x10 <sup>-3</sup> | Area Ratio | Outlet Spacing<br>(m) | Discharge<br>(m <sup>3</sup> /s) x10 <sup>-3</sup> | Uniformity Coefficient | Velocity, v<br>(m/s) | Kinematic Viscosity<br>(m <sup>2</sup> /s) x 10 <sup>-6</sup> | Re    |
|-------------|--------------|---|------------|-----------------------|--|------------------------|----------------------|---|-------|
| Inch<br>(") | Meter<br>(m) |   |            |                       |  |                        |                      |   |       |
| 0.5         | 0.0127       | 0.127   | 1.00       | 1.1                   | 0.566  | 0.74                   | 4.4657               | 0.7867  | 72091 |
|             |              |   |            | 2.2                   | 0.520  |                        | 4.0945               |   | 66099 |
|             |              |   |            | 3.3                   | 0.468  |                        | 3.6824               |   | 59446 |
|             |              |   |            | 4.4                   | 0.419  |                        | 3.2992               |   | 53260 |

**Appendix B2: Calculated Data for 1.0” Pipe**

| Diameter    |              | Main Pipe Area<br>(m <sup>2</sup> ) x10 <sup>-3</sup> | Area Ratio | Outlet Spacing<br>(m) | Discharge<br>(m <sup>3</sup> /s) x10 <sup>-3</sup> | Uniformity Coefficient | Velocity, v<br>(m/s) | Kinematic Viscosity<br>(m <sup>2</sup> /s) x 10 <sup>-6</sup> | Re    |
|-------------|--------------|---|------------|-----------------------|--|------------------------|----------------------|---|-------|
| Inch<br>(") | Meter<br>(m) |   |            |                       |  |                        |                      |   |       |
| 1.0         | 0.0254       | 0.507   | 0.50       | 1.1                   | 0.736  | 0.99                   | 1.4510               | 0.7581  | 48615 |
|             |              |   |            | 2.2                   | 0.721  |                        | 1.4221               |   | 47647 |
|             |              |   |            | 3.3                   | 0.515  |                        | 1.0158               |   | 34034 |
|             |              |   |            | 4.4                   | 0.730  |                        | 1.4398               |   | 48240 |

**Appendix B3: Calculated Data for 1.5" Pipe**

| Diameter    |              | Main Pipe Area<br>(m <sup>2</sup> ) x10 <sup>-3</sup> | Area Ratio | Outlet Spacing<br>(m) | Discharge<br>(m <sup>3</sup> /s) x10 <sup>-3</sup> | Uniformity Coefficient | Velocity, v<br>(m/s) | Kinematic Viscosity<br>(m <sup>2</sup> /s) x 10 <sup>-6</sup> | Re    |
|-------------|--------------|---|------------|-----------------------|--|------------------------|----------------------|---|-------|
| Inch<br>(") | Meter<br>(m) |   |            |                       |  |                        |                      |   |       |
| 1.5         | 0.0381       | 1.140   | 0.33       | 1.1                   | 0.814  | 0.98                   | 0.7143               | 0.7867  | 34593 |
|             |              |   |            | 2.2                   | 0.673  |                        | 0.5901               |   | 28578 |
|             |              |   |            | 3.3                   | 0.791  |                        | 0.6939               |   | 33605 |
|             |              |   |            | 4.4                   | 0.797  |                        | 0.6988               |   | 33842 |

**Appendix B4: Calculated Data for 2.0" Pipe**

| Diameter    |              | Main Pipe Area<br>(m <sup>2</sup> ) x10 <sup>-3</sup> | Area Ratio | Outlet Spacing<br>(m) | Discharge<br>(m <sup>3</sup> /s) x10 <sup>-3</sup> | Uniformity Coefficient | Velocity, v<br>(m/s) | Kinematic Viscosity<br>(m <sup>2</sup> /s) x 10 <sup>-6</sup> | Re    |
|-------------|--------------|---|------------|-----------------------|--|------------------------|----------------------|---|-------|
| Inch<br>(") | Meter<br>(m) |   |            |                       |  |                        |                      |   |       |
| 2.0         | 0.0508       | 2.027   | 0.25       | 1.1                   | 0.761  | 1.02                   | 0.3754               | 0.7867  | 24241 |
|             |              |   |            | 2.2                   | 0.813  |                        | 0.4012               |   | 25907 |
|             |              |   |            | 3.3                   | 0.751  |                        | 0.3705               |   | 23924 |
|             |              |   |            | 4.4                   | 0.781  |                        | 0.3853               |   | 24880 |

**Appendix B5: Calculated Data for 3.0" Pipe**

| Diameter    |              | Main Pipe Area<br>(m <sup>2</sup> ) x10 <sup>-3</sup> | Area Ratio | Outlet Spacing<br>(m) | Discharge, q<br>(m <sup>3</sup> /s) x10 <sup>-3</sup> | Uniformity Coefficient | Velocity, v<br>(m/s) | Kinematic Viscosity<br>(m <sup>2</sup> /s) x 10 <sup>-6</sup> | Re    |
|-------------|--------------|---|------------|-----------------------|---|------------------------|----------------------|---|-------|
| Inch<br>(") | Meter<br>(m) |   |            |                       |   |                        |                      |   |       |
| 3.0         | 0.0762       | 4.560   | 0.17       | 1.1                   | 0.682   | 1.03                   | 0.1496               | 0.7867  | 14490 |
|             |              |   |            | 2.2                   | 0.704   |                        | 0.1545               |   | 14965 |
|             |              |   |            | 3.3                   | 0.680   |                        | 0.1491               |   | 14442 |
|             |              |   |            | 4.4                   | 0.706   |                        | 0.1548               |   | 14994 |

### Appendix B6: Resistance Coefficient, k

| Diameter |           | Area Ratio | Outlet Spacing (m) | Head Loss (m) | k <sub>experimental</sub> | Average k <sub>experimental</sub> | k <sub>theoretical</sub> |
|----------|-----------|------------|--------------------|---------------|---------------------------|-----------------------------------|--------------------------|
| Inch (") | Meter (m) |            |                    |               |                           |                                   |                          |
| 0.5      | 0.0127    | 1.00       | 1.1                | 0.3000        | 0.2951                    | NA                                | 1.62                     |
|          |           |            | 2.2                | -             | -                         |                                   |                          |
|          |           |            | 3.3                | -             | -                         |                                   |                          |
|          |           |            | 4.4                | -             | -                         |                                   |                          |
| 1.0      | 0.0254    | 0.5        | 1.1                | 0.1000        | 0.9319                    | 0.94                              | 1.38                     |
|          |           |            | 2.2                | 0.0900        | 0.8731                    |                                   |                          |
|          |           |            | 3.3                | 0.0533        | 1.0135                    |                                   |                          |
|          |           |            | 4.4                | 0.1000        | 0.9464                    |                                   |                          |
| 1.5      | 0.0381    | 0.33       | 1.1                | 0.0057        | 0.2192                    | 0.43                              | 1.26                     |
|          |           |            | 2.2                | 0.0060        | 0.3381                    |                                   |                          |
|          |           |            | 3.3                | 0.0167        | 0.6805                    |                                   |                          |
|          |           |            | 4.4                | 0.0123        | 0.4942                    |                                   |                          |
| 2.0      | 0.0508    | 0.25       | 1.1                | 0.0013        | 0.1810                    | 0.55                              | 1.14                     |
|          |           |            | 2.2                | 0.0077        | 0.9386                    |                                   |                          |
|          |           |            | 3.3                | 0.0040        | 0.5717                    |                                   |                          |
|          |           |            | 4.4                | 0.0040        | 0.5286                    |                                   |                          |
| 3.0      | 0.0762    | 0.17       | 1.1                | 0.0000        | 0.0000                    | 0.00                              | 1.08                     |
|          |           |            | 2.2                | 0.0000        | 0.0000                    |                                   |                          |
|          |           |            | 3.3                | 0.0000        | 0.0000                    |                                   |                          |
|          |           |            | 4.4                | 0.0000        | 0.0000                    |                                   |                          |

## APPENDIX C      SAMPLE CALCULATION

A sample calculation for the analysis result is shown below. The calculations are based on the experiment with water level equal to 1.70m using 0.0254m (1”) main pipe diameter and 0.0127m lateral pipe diameter with 1.1m spacing between each outlet. Calculation for other experiments is following the same steps stated below.

Area of main pipe is calculated using formula  $A = \frac{\pi d^2}{4}$ , where A and D are previously defined in equation 3.1. A sample calculation for A is as follow:

$$\begin{aligned} A &= \frac{\pi(0.0254)^2}{4} \\ &= 0.507 \times 10^{-3} \text{ m}^2 \end{aligned}$$

Area ratio is calculated by dividing lateral pipe diameter with main pipe diameter as follow:

$$\text{Area ratio} = \frac{0.0127}{0.0254} = 0.50$$

Discharge, Q is calculated by using formula  $Q = \frac{V}{t}$ , where Q, V and t are previously defined in equation 2.8. A sample calculation for Q is as follow:

$$\begin{aligned} Q &= \frac{22.07/1000}{30} \\ &= 0.736 \times 10^{-3} \text{ m/s} \end{aligned}$$

$Q_T$  is then obtained by summing up  $Q_1$ ,  $Q_2$ ,  $Q_3$ , and  $Q_4$ .

$$Q_T = Q_1 + Q_2 + Q_3 + Q_4$$

$$= 0.736 + 0.721 + 0.515 + 0.730$$

$$= 2.702 \text{ m/s}$$

Uniformity coefficient is calculated by dividing discharge of the last manifold segment before the dead end with discharge of the last manifold segment that previously defined in equation 2.11. A sample calculation for uniformity coefficient is as follow:

$$\text{uniformity coefficient} = \frac{0.730}{0.736} = 0.99$$

Velocity,  $v$  is calculated by using Continuity Equation  $v = \frac{Q}{A}$ , where  $Q$ ,  $v$  and  $A$  are previously defined in equation 2.7. A sample calculation for  $v$  is as follow:

$$\text{velocity} = \frac{0.736 \times 10^{-3}}{0.507 \times 10^{-3}} = 1.4510 \text{ m/s}$$

Kinematic viscosity is based on the temperature measured from the experiment. The value is in SI units as in Appendix C1.

#### Appendix C1: Dynamic and Kinematic Viscosity of Water in SI Unit

| Temperature, $t$ (°C) | Dynamic Viscosity, $\mu$ (Ns/m <sup>2</sup> ) x 10 <sup>-3</sup> | Kinematic Viscosity, $\nu$ (m <sup>2</sup> /s) x 10 <sup>-6</sup> |
|-----------------------|--|---|
| 0                     | 1.787  | 1.787   |
| 5                     | 1.519  | 1.519   |
| 10                    | 1.307  | 1.307   |
| 20                    | 1.002  | 1.004   |
| 30                    | 0.798  | 0.801   |
| 40                    | 0.653  | 0.658   |
| 50                    | 0.547  | 0.553   |
| 60                    | 0.467  | 0.475   |
| 70                    | 0.404  | 0.413   |
| 80                    | 0.355  | 0.365   |
| 90                    | 0.315  | 0.326   |
| 100                   | 0.282  | 0.294   |

(Source: Retrieved from <http://www.engineersedge.com>)

Kinematic viscosity is calculated as follow:

$$\text{Kinematic Viscosity for } 30^\circ = 0.801 \text{ m/s}$$

$$\text{for } 40^\circ = 0.658 \text{ m/s}$$

$$0.801 - 0.658 = 0.143$$

$$\frac{0.413}{10} = 0.0143$$

$$\begin{aligned} \therefore \text{Kinematic viscosity for } 33^\circ &= 0.801 - (0.0143 \times 3) \\ &= 0.7581 \times 10^{-6} \text{ m}^2/\text{s} \end{aligned}$$

Reynolds Number,  $Re$  is calculated by using  $Re = \frac{vD}{\nu}$  where  $v$ ,  $D$  and  $\nu$  are previously defined in equation 3.2. A sample calculation for  $Re$  is as follows:

$$Re = \frac{1.4510 \times 0.0254}{0.7581 \times 10^{-6}} = 48615 \text{ (turbulence)}$$

$Re$  is divided into three categories which are laminar, transient and turbulence.  $Re$  value for laminar flow is less than 2000, value 2000 to 4000 is in transient flow and turbulent flow have  $Re$  greater than 4000.

Experimental Resistance coefficient,  $k$  is calculated by the formula as follows:

$$h_L = k \frac{v^2}{2g}$$

$$k_{exp} = \frac{0.10 (2 \times 9.81)}{1.4510^2} = 0.9319$$

While Theoretical Resistance coefficient,  $k$  is calculated by the equation 2.13 as follows:

$$k = \left(\frac{L_e}{D}\right) f t$$

$$k_{\text{theoretical}} = (60)(0.023) = 1.38$$

where  $\frac{L_e}{D}$  is obtained from the Table 2.2 and  $f t$  is from Table 2.3 according to the type of fittings and pipe diameter.

