CHAPTER I
INTRODUCTION

1.1 Background

Fluid flow is one of the essential subjects in chemical engineering that discusses the behavior of fluids under dynamic conditions. karena teknik kimia erat kaitannya dengan proses, dan proses secara tersirat menjelaskan perubahan serta pada dasarnya bersifat dinamis.

In this experiment, we simulate liquid flow in a closed systemwater is pumped through pipes from a lower point to a higher point. In practice, fluid flow in a piping system can face various problems that can affecting flow efficiency. hese losses are caused by the characteristics of the piping system itself (Bachrun et al., 2021). For example, a piping system may be equipped with fittings such as valves, elbows, expansions, contractions, tees, and manometers (Geankoplis, 1993). In this type of piping system, the phenomenon of head loss is something that must be carefully considered. Head loss occurs due to resistance experienced by the fluid during flow, whether caused by friction between the fluid and the pipe wall or by disturbances from additional components such as joints and pipe accessories.

The liquid used in this experiment is water stored in a tank to allow for recycling. The application of the principle of mass transfer is carried out by calculating the flow rate regulated by valve opening, while the application of momentum transfer is demonstrated through the driving force of the pump that circulates the liquid, where the head loss value can be calculated based on the condition of the pipe and fittings through which the fluid passes.

1.2 Problem Statement

This experiment uses the Fluid Friction Measurement Apparatus FM100. The fluid flow experiment setup includes a water tank, pump, piping system, manometer, and pressure transmitter as instruments to measure head loss. Students are expected to be able to operate and stop the equipment, collect experimental data, adjust flow rate for flow rate calculations, determine Reynolds number, calculate head loss, and determine the friction factor for both straight pipes and fittings.

1.3 Experiment Objectives

The objectives of this experiment are:

1. To calculate the flow rate using the available measuring instruments.
2. To determine the Reynolds number for each variation of flow rate.
3. To calculate head loss from the flow using readings from the manometer or pressure transmitter.
4. To calculate the K-factor of fittings such as 90° bend, 90° elbow, 45° elbow, 45° Y (135° flow), 45° Y (180° flow), 90° T (90° flow), 90° T (180° flow), sudden enlargement, sudden contraction, and inline strainer.
5. To calculate the K-factor for gate valves and globe valves.
6. To explain the relationship between head loss and velocity head.
7. To explain the relationship between flow rate, Reynolds number, and head loss.

1.4 Practicum Benefits

Through this experiment, students will gain knowledge regarding fluid flow in piping systems and factors affecting it, such as Reynolds number, fittings, and head loss. They will also develop skills in operating fluid flow systems, such as reading measuring instruments (manometer) and adjusting flow rates.

CHAPTER II
LITERATURE REVIEW

2.1 Definition of Fluids

Fluids are substances that can flow. Liquids naturally flow from a higher location to a lower one or from higher to lower pressure. Gases, on the other hand, flow naturally from high to low pressure. Fluids can be categorized into liquids and gases. In liquids, molecules are closely packed, giving them a definite volume and preventing them from filling a space larger than their volume. Gases have freely moving molecules that fill the entire volume of a container (Rodgers, 2013). If these conditions are not fulfilled, the fluid needs to be moved using external energy such as pumps for liquids and fans, blowers, or compressors for gases.

2.2 Classification of Fluid Flow

From the perspective of how pressure changes affect it, fluid flow can be classified into two types:

1. Fluida tak mampat (*incompressible*)

   These are fluids that, when pressure changes occur during a process, do not experience changes in their physical properties. For example, if the pressure changes but the volume remains the same, the density also stays constant. This category includes stable liquid-phase fluids such as water, mercury, oils, and other liquids.

2. Fluida mampat (*compressible*)

   These are fluids that, when pressure changes occur, also experience a change in volume, which in turn changes their density. This category includes gas-phase fluids such as air, steam, and other gases.

From the perspective of viscosity, liquids can be divided into two types:

1. Newtonian fluids

   These are liquids where the relationship between shear stress and the rate of deformation (velocity gradient) is linear, meaning it forms a straight-line relationship. The viscosity of these fluids remains constant regardless of the shear rate applied. In other words, their viscosity does not change even when the shear rate changes. Examples include low-viscosity or thin liquids such as water.

2. Non-Newtonian fluids

   These are liquids where the relationship between shear stress and the rate of deformation is non-linear, forming a curved relationship. Their viscosity changes with the shear rate and may also depend on other factors such as time and temperature. Examples include thick or viscous fluids such as toothpaste and ketchup.

From the perspective of flow rate stability, fluids flow can divided by two types:

1. Steady-state flow:

   The flow rate remains constant over the period being observed.

2. Unsteady-state flow

   The flow rate changes over time

On the other hand, from the perspective of turbulance fluids flow can divided by two types:

1. Laminar flow

   Fluid particles move in parallel paths at low velocity, so no turbulence occurs.

2. Turbulent flow

   Fluid particles move in irregular paths at high velocity, creating turbulence. (Ghurri, 2014)

2.3 Fluid Friction in Smooth Pipes

Osborne Reynolds demonstrated that two types of flow can occur in a pipe:

1. Laminar flow at low velocities, where head loss is represented by h and fluid velocity is represented by u.
2. Turbulent flow at higher velocities.

These two flow types are separated by a transitional phase, in which there is no clear relationship between h and u. The plots of h versus u and log h versus log u show these zones (Figures 2.1 and 2.2)

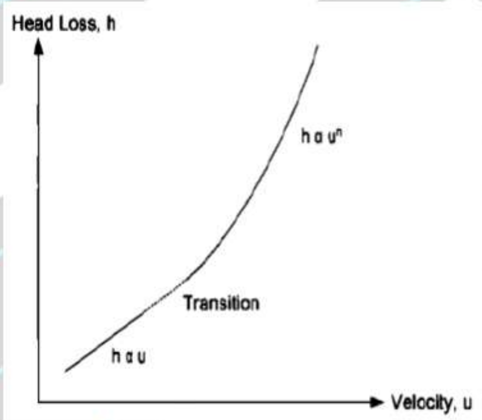


Figure 2.1 Relationship between head Loss and flow Rate

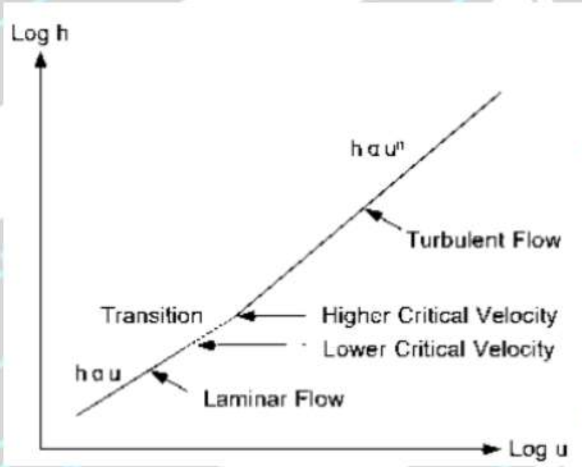


Figure 2.1 Relationship between Log u dan Log h

2.4 *Head Loss* karena Gesekan melalui Pipa

For a circular pipe flowing at full capacity, the head loss due to friction (mH_2O) can be calculated using the following formula:

$$h = \frac{4fLu^2}{2gd} \text{ atau } \frac{\lambda Lu^2}{2gd} \tag{2.1}$$

Description:

L = length of pipe between tapping points (m) — 1 m for all pipes

d = internal diameter of the pipe (m)

u = average water velocity through the pipe (m/s)

g = 9.81 (acceleration due to gravity, m/s^2)

f = pipe friction coefficient (British)

$4f = \lambda$ (American) (Giles, 1997)

Once the Reynolds number (*Re*) for the pipe flow is determined, the value of *f* can be obtained from the Moody diagram.

$$Re = \frac{\rho ud}{\mu} \tag{2.2}$$

μ = *molecular viscosity*

= $1{,}15 \times 10^{-3}$ Ns/m^2 pada 15^0C

ρ = density

= 999 kg/m^3 pada 15^0C

(Hariyanto *et al*., 2016)

2.5 Head Loss through Fitting

A piping installation consists of various components such as bends, elbows, tees, and valves, all of which create resistance to flow. The head loss in these fittings is proportional to the velocity head of the fluid flowing through them

$$h = \frac{Ku^2}{2g} \tag{2.2}$$

Description:

h = head loss across all fittings (mH_2O)

K = fitting factor

u = average water velocity through the pipe (m/s)

g = 9.81 (acceleration due to gravity, m/s^2

(Zainudin *et al*., 2012)

2.6 Flow Measurement Using Head Differential

2.6.1 Pitot Static Tube

Pitot tube (named after Henri Pitot in 1732) measures fluid velocity by converting the kinetic energy of the flow into potential energy. This conversion takes place at the stagnation point, located at the Pitot tube's inlet (Figure 2.3). The resulting pressure, which is higher than the free-stream (dynamic) pressure, comes from this conversion of kinetic to potential energy. This 'static' pressure is measured by comparing it to the flow's dynamic pressure using a differential manometer.

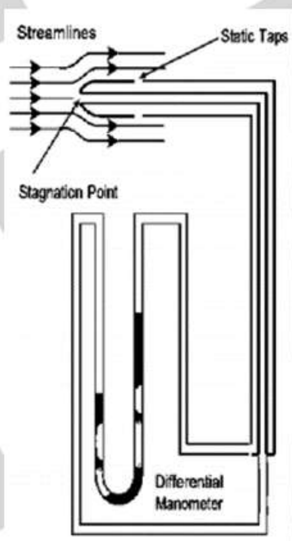


Figure 2.2 Tipe pitot static tube

For incompressible fluids, Bernoulli's equation describes the relationship between velocity and pressure along a streamline

$$\frac{\rho}{\rho g}+\frac{v^2}{2g}+z=h^*=\text{constant} \tag{2.4}$$

Description:

p = static pressure of the fluid at the cross-section

ρ = density of the flowing fluid

g = acceleration due to gravity

v = average flow velocity at the cross-section

z = elevation head at the cross-section relative to the datum

h = total head loss (Zainudin *et al*., 2012)

When evaluated at two different points along the streamline, Bernoulli's equation gives,

$$\frac{p_1}{\rho\, g}+\frac{{v_1}^2}{2g}+z_1=\frac{p_2}{\rho\, g}+\frac{{v_2}^2}{2g}+z_2 \tag{2.5}$$

If $z_1 = z_2$ and point 2 is the stagnation point (i.e., $v_2 = 0$), the above equation becomes,

$$\frac{{v_1}^2}{2}+\frac{p_1}{\rho}=\frac{p_2}{\rho} \tag{2.6}$$

Therefore, the flow velocity can be obtained as,

$$v_1=\sqrt{\frac{2(p_2-p_1)}{\rho}} \tag{2.7}$$

Or more spesifically,

$$v=\sqrt{\frac{2(p_{stagnation}-p_{static})}{\rho}} \tag{2.8}$$

(Beck *et al*., 2010; Cimbala & Cengel, 2004)

A piping installation consists of various components such as bends, elbows, tees, and valves, all of which create resistance to flow. The head loss in a piping system is proportional to the velocity head of the fluid passing through the fittings

2.6.2 Venturi meter

A Venturi meter consists of a Venturi tube and a differential pressure gauge. The Venturi tube has a converging section, a throat, and a diverging section, as shown in the figure below. The function of the converging section is to increase the fluid velocity and reduce its static pressure. This creates a pressure difference between the inlet and the throat, which is correlated with the flow rate. The diverging cone serves to restore the flow area back to the inlet size and convert the velocity head back into pressure head.

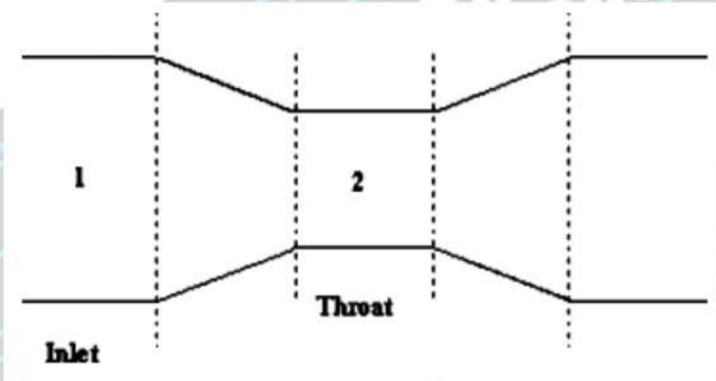


Figure 2.3 Tabung venturi

By applying the continuity equation $Q = A_1V_1 = A_2V_2$ to Equation (2.5), it becomes,

$$\frac{p_1 + p_2}{\gamma} + Z_1 - Z_2 = \frac{v_2^{\,2}}{2g}\left[1 - \left(\frac{A_2}{A_1}\right)^2\right] \tag{2.9}$$

In an ideal case,

$$Q_i = A_2V_2 = A^2\left[1 - \left(\frac{A_2}{A_1}\right)^2\right]^{-\frac{1}{2}}\left[2g\left(\frac{p_1 + p_2}{\gamma} + Z_1 - Z_2\right)\right]^{\frac{1}{2}} \tag{2.10}$$

However, in the case of real fluid flow, the flow rate is expected to be lower than that given by Equation (2.10) due to friction effects and the resulting head loss between the inlet and the throat.

$$Q_a = C_d \text{ x } A_2 \text{ x}\left[1 - \left(\frac{A_2}{A_1}\right)^2\right]^{-\frac{1}{2}}\left[2g\left(\frac{p_1 + p_2}{\gamma} + Z_1 - Z_2\right)\right]^{\frac{1}{2}} \tag{2.11}$$

In measurement practice, these non-idealities are accounted for by introducing an experimentally determined discharge coefficient, *Cd*, known as the discharge coefficient. With $Z_1 = Z_2$ in this apparatus, the discharge coefficient is:

$$C_d = \frac{Q_a}{Q_1} \tag{2.12}$$

Koefisien pelepasan, Cd biasanya terletak pada kisaran antara 0,9 dan 0,99 (Aisyah, 2020).

2.6.3 *Orifice Plate*

An orifice, used as a metering device in piping, consists of a concentric, square-edged circular hole in a thin plate, which is clamped between pipe flanges as shown in the figure below.

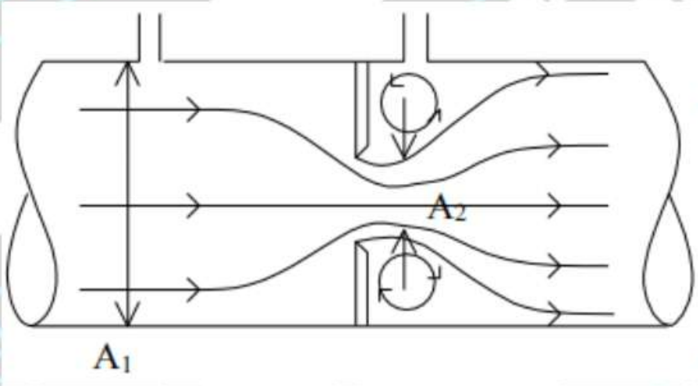


Figure 2.4 Orifice plate

Pressure taps for installing separate pressure gauges are made through holes in the pipe wall on both sides of the orifice plate. The downstream pressure tap is placed at the location of minimum pressure, which is assumed to be at the vena contracta. The center of the upstream pressure tap is located between half and two pipe diameters from the upstream side of the orifice plate; typically, a distance of one pipe diameter is used. Equation (2.11) for the Venturi meter can also be applied to the orifice meter, where the actual flow rate,

$$Q_a = C_d \text{ x } A_2 \text{ x} \left[1 - \left(\frac{A_2}{A_1}\right)^2\right]^{-\frac{1}{2}} \left[2g\left(\frac{p_1 - p_2}{\gamma}\right)\right]^{\frac{1}{2}} \tag{2.13}$$

The discharge coefficient, *Cd*, in the case of an orifice meter will be different from that of a Venturi meter (Bansal, 2010).

2.6 *Fitting*

In a piping system, fittings refer to components used to connect sections of pipe, direct the flow, control the flow, or close the end of a pipe. In addition, fittings allow changes in the piping route, branching of pipes, and variations in pipe diameter.

Components in a piping system that fall under the category of fittings include:

1. Tee

Tee is one type of pipe fitting that serves as a connector between three pipe branches or more. A tee with four branches is called a crossflow, as shownin Figure 2.6

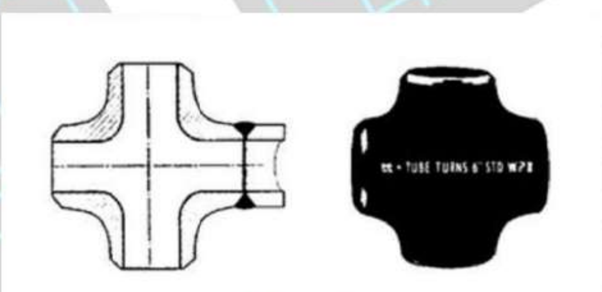


Figure 2.5 Crossflow tee

(Sherwood, 1973)

Tees can be classified based on the angle of direction change: 45° (lateral tee) and 90°. In addition, based on the connected diameters, they can be categorized as equal tees or reducing tees, as shown in Figures 2.7 and 2.8 below.

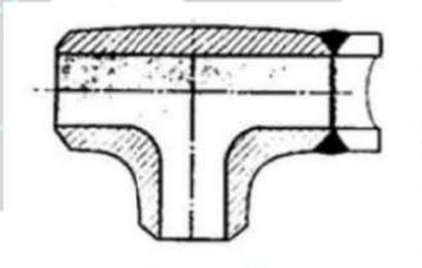
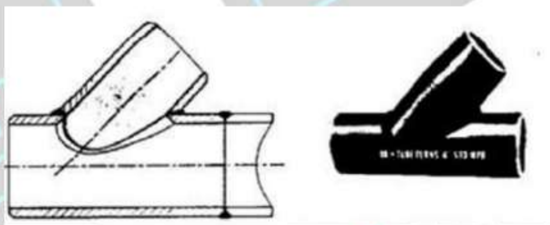


Figure 2.6 Equal tee

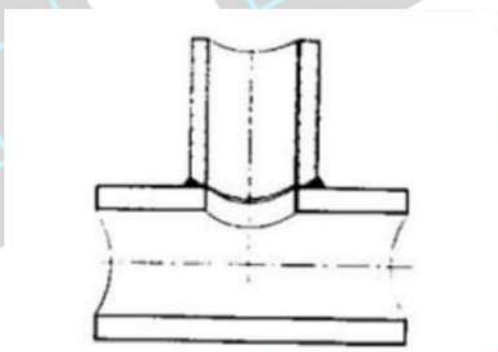
(Sherwood, 1973)



(Sherwood, 1973)

Figure 2.8 Lateral tee

Terdapat juga jenis *tee* yang disebut *stub-in*, yang langsung disambungkan ke pipa melalui pengelasan tanpa memerlukan sambungan tambahan, seperti yang ditunjukkan pada Figure 2.9 berikut



(Sherwood, 1973)

Figure 2.7 Stub-in tee

2. *Elbow*

An elbow is used to change the direction of the piping route and add flexibility. Elbows can be classified based on the change in direction angle—45°, 90°, and 180° (U-turn) each available in short radius (SR) and long radius

(LR) types. These types of elbows are shown in Figure 2.10.

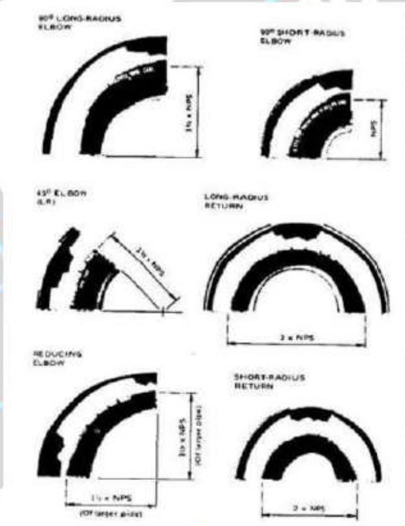


Figure 2.8 Types of elbow

(Sherwood, 1973)

3. *Reducer*

Reducer berfungsi untuk menghubungkan dua pipa dengan diameter yang berbeda. Terdapat 2 jenis *reducer: concentric reducer dan eccentric reducer.*

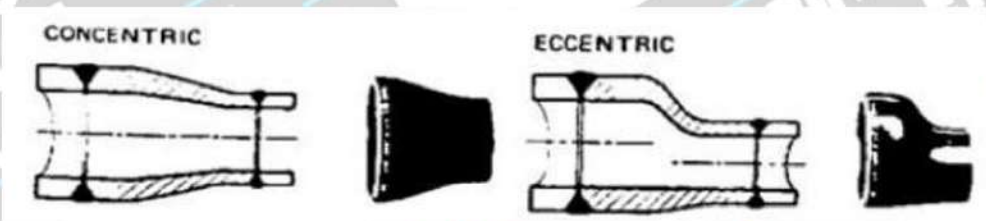


Figure 2.9 Concentric reducer dan eccentric reducer

(Sherwood, 1973)

4. *Cap*

A cap is used to stop the flow in a pipe or to close the end of a pipe line. Caps are located at the end of a piping system. Based on shape and connection method, caps can be classified as butt-weld caps or flat closure caps.

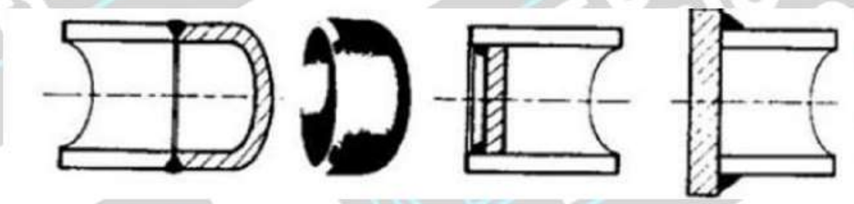


Figure 2.10 Types cap

(Sherwood, 1973)

CHAPTER III
METHODOLOGY

3.1 Experimental Design

3.1.1 Practical Framework

1. The apparatus used is a closed-loop liquid flow system (water) consisting of straight pipes, fittings, and a pump.
2. The piping system includes a recycling feature to keep the pump operating steadily.
3. It is also equipped with valves to control the flow rate, which can then be used to calculate the flow rate and Reynolds number.
4. A manometer is installed to measure head loss in both straight pipes and fittings for each variation of Reynolds number.
5. The experiment also involves calculating the friction factor for straight pipes and the equivalent length for fittings.

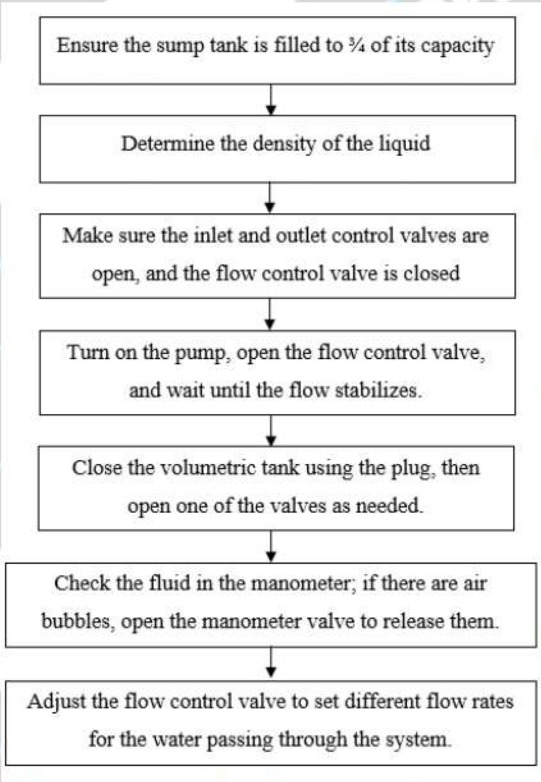


Figure 3.1 Scheme of practical setup

3.1.2 Variable Determination

1. Independent variables:
   - Type of pipe
   - Type of fitting
   - Gate valve
   - Flow rate (L/min)
2. Dependent variabel :

   Head loss measured by the pressure transmitter and height difference on the manometer

3.2 Materials and Equipment Used

3.2.1 Materials

The materials that used is aquadest

3.2.2 Equipment

The equipment used in the fluid flow experiment is divided into two parts:

a. Primary equipmentss, which includes:
   1. Tank
   2. Pump
   3. Piping system, consisting of straight pipes, joints, bends, valves, expansions, and contractions
   4. Manometer with water as the measuring medium

b. Supporting equipment, which includes:
   1. Pycnometer for determining the fluid's density
   2. Stopwatch for measuring time

3.3 Equipment Setup

Figure 3.2 Instuments set up (ApparatusFM 100)

Figure description:

1. 7.5 mm smooth pipe
2. 10 mm smooth pipe
3. Sudden construction
4. 17 mm smooth pipe
5. 17 mm roughened pipe
6. Global Valve
7. Gate Valve
8. Inlet control valve
9. Pressure Transmitter
10. Inline Strainer
11. 45º Elbow
12. 45º Y
13. 90º Elbow
14. 90º Y
15. 90º T
16. Pitot Static Tube
17. Orifice Meter
18. Venturi Meter
19. Manometer
20. Sudden Enlargement
21. Outlet Control Valve

Figure 3.3 Instuments set up (ApparatusFM 100)

1. Open channel
2. Working bench
3. Main switch
4. Flow control valve
5. Centrifugal pump
6. Plug
7. Volumetric tank
8. Level sight tube
9. Sump tank
10. Drain valve
11. Lockable castor wheel

3.4 Practicum Procedure

The experiment procedure can be divided into two stages:

A. Preparation Stage

1. Ensure the sump tank is filled to ¾ of its capacity.
2. Determine the density of the liquid to be used in the experiment.
3. Make sure the inlet control valve and outlet control valve are open.
4. Ensure the flow control valve is closed.

B. Operation Stage

1. Turn on the pump, open the flow control valve, and wait until the flow becomes steady.
2. Close the volumetric tank using the plug.
3. Open one of the valves (according to the variable) and measure the flow rate.
4. Check the liquid in the manometer; if there are air bubbles, open the manometer valve to release them.

5. Adjust the flow control valve to vary the water flow rate through the piping system and calculate the corresponding Reynolds number.
6. Repeat step 2 with different flow control valve openings (until you obtain Reynolds number variations for laminar, transitional, and turbulent flows).
7. Record the manometer readings according to the given variable.
8. Create a results table (flow rate, Reynolds number according to the variable)

REFERENCES

Bachrun, R., Pallu, M. S., Thaha, M. A., & Bakri, B. (2021). The effect of discharge on head loss with straight and bend flow directions in the pipeline. *IOP Conference Series: Earth and Environmental Science, 841*(1), 012017. https://doi.org/10.1088/1755-1315/841/1/012017

Bansal, R. K. (2010). *A Text Book of Fluid Mechanics and Hydraulic Machines* (Revised 9th ed). New Delhi: Laxmi Publication (P) Ltd.

Beck, B. T., Payne, G., & Heitman, T. (2010). The aerodynamics of the pitot-static tube and its current role in non-ideal engineering applications. *American Society for Engineering Education*, https://doi.org/15.1204.1-15.1204.16.

Cimbala, J. M., & Cengel, Y. A. (2004). *Fluid Mechanics: Fundamentals and Applications* (4th ed.). New York: Mc Graw Hill Book Co.

Ghuri, A. (2014). *Dasar-Dasar Mekanika Fluida*. Teknik Mesin: Universitas Udayana.

Rodgers, T. (2013). *Fluid Flow*. Department of Chemical Engineering, University of Manchester, United Kingdom, 1-81.

Geankoplis, C.J. (1993). *Transport Process and Unit Operation* (3rd ed.). Prentice Hall Inc., Englewood Cliffs, New Jersey.

Giles, Ronald. (1997). *Fluid Mechanics and Hydraulic* (2nd ed.). New York: McGraw Hill Book Co.

Hariyono, Rubiono, G., dan Mujitano, H. (2016). Studi eksperimental perilaku aliran fluida pada sambungan belokan pipa. *Jurnal Prodi Teknik Mesin*, *1*(1), 12-17.

Sherwood, D.R. (1973). *The PIPING GUIDE FOR THE DESIGN AND DRAFTING OF INDUSTRIAL PIPING SYSTEMS* (2nd ed.). Syentek Inc.

Zainudin, Z., Sayoga, I. M. A., & Nuarsa, M. (2012). Analisa pengaruh variasi sudut sambungan belokan terhadap head losses aliran pipa. *Dinamika Teknik Mesin*, *2*(2), 127-132.