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The effect of discharge on head loss with straight and bend flow directions in the pipeline

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Abstract. Piping flow is a way of transportation to carry material from one place to another. A problem in pipelines is a head loss. This head loss can affect pipe capacity and reduce flow discharge. Structure or geometry of pipelines will affect energy due to the roughness of pipe walls, friction, bends, joints and energy decreases with the length of passed pipe. Head loss in the piping system includes major and minor energy losses. The objective of this research is to determine the magnitude of major and minor head losses and to determine the relationship between discharge and velocity, pressure height, and the influence of geometric network structure. The variation of flowed discharge is 0.5 liter/second, 2.5 liter/second, 3 liter/second and 4 liter/second. The research is experimental research conducted in the laboratory. The test design uses a pipeline with a length of 6 m, a width of 1.20 m, and a dimension of 64 mm. The results showed that an increase in flow rate (Q) followed by an increase in flow velocity (v) will increase Reynold's (Re) number so that the head loss in the pipeline will increase. The increasing of Reynold's (Re) number will decrease the value of the friction coefficient. Structure or geometric of the line also influences the pattern of flow. In a straight pipe, the velocity of flow is large but the pressure height is small compared to the bend pipe flow where the velocity of flow is small but the pressure height is larger.

1. Introduction

The pipe is a closed channel with a circular cross-section and it is used to drain fluid. Fluid flow can be full cross-sectional or half flow depending on the size of the discharge or rate. In the pipe system, there are many problems experienced by the flow in it. In a flow that passes through a pipeline system or installation, there will be flow resistance due to factors of pipeline installation itself such as cross-section (dimension of pipe, bends, joints) and changes in surface roughness. In addition to these factors, the fluid flowing within the boundary (pipe or plane) will occur shear stress and velocity gradient across the flow field due to viscosity. Shear stress will cause a head loss during flow [1].

Head losses can be divided into 2 (two) namely, major losses and minor losses. Major losses are losses in the piping system due to fluid friction with the longitudinal pipe wall. Minor losses are losses in the piping system due to pipe joints [2].

The distribution of flow pressure in a rectangular section with a 90° bend with a horizontal position in the large pipe (inlet) and vertical position in the small pipe (outlet) there is an increase in pressure when passing through the bend (elbow) due to flow slowdown [3]. Research on pressure loss in bends where the decrease of pressure increases with increasing discharge conducted by [4]. Tube bundles to

minimize separation in pipe bends to reduce head losses in the pipe. The fluid flow that flows through the bend of the pipe causes a separation that has been used by [5]. Separation results in vortex, vibration, and cavitation, where these losses result in increased head losses and have the potential to damage the pipe installation so that the separation needs to be eliminated.

The objective of this research is to determine the amount of head loss which is influenced by the variation of discharge, to determine the relationship between head loss and flow rate, flow velocity and Reynold's (Re) number, the relationship between flow velocity and pressure level in the straight and bend flows direction.

2. Literature Review

2.1. Basic properties of the fluid

The fluid is a fluid that can flow, has particles that are easy to move, and change shape without substance separation. According to Triatmodjo, that in general, fluids have basic properties that are important inflow. Density shows the mass of liquid per unit volume. The relationship can be stated as equation 1.

$$\rho = \frac{m}{v} \quad (1)$$

m is the mass of fluid (kg), V is the volume of fluid (m³). The value of density can be influenced by temperature; the higher of temperature, the less velocity of a fluid due to the reduced cohesion force of the molecules.

Specific gravity shows that each unit volume is the weight of the object. The weight of an object is a product of mass and gravity acceleration. There is a relationship between specific gravity and density in the following equation 2.

$$y = \rho \cdot g \quad (2)$$

y is specific gravity (N/m³), ρ is density (kg/m³) and g is gravity acceleration (m/d²). Viscosity is a property of a liquid to resist shear stress when moving/flowing. The ideal liquid has no viscosity. Kinematic viscosity is shown in equation 3.

$$v = \frac{\mu}{\rho} \quad (3)$$

v is kinematic viscosity (m²/d), μ is the value of dynamic viscosity (kg.m/s), ρ is the fluid mass density (kg/m³).

2.2. Discharge (Q)

The amount of liquid flowing through the flow section per one unit of time is called the flow rate. The calculation of flow rate can use equation 4 [6].

$$Q = \frac{v}{t} \quad (4)$$

Q is rate/discharge (m³/sec), v is volume (m³), t is time (seconds).

2.3. Velocity (v)

The measurement of flow velocity using a Pitot tube, L-shaped Pitot (Pitot tube) in a flowing liquid with one end facing the direction of the flow, while the other end is upward and in direct contact with the outside air (atmospheric pressure). In Triatmodjo, the equation for velocity is shown in equation 5.

$$v = \sqrt{2gh} \quad (5)$$

v is flow velocity (m/sec), g is gravity acceleration (m/d²), h is pressure level in Pitot tube (m).

2.4. Reynold's (Re) number

The flow pattern that occurs in a closed channel varies depending on individual observations and the conditions of the flowing fluid, for a particular flow situation. In 1884 Reynolds, Triatmodjo, there were 3 (three) factors that influence the flow state, namely the viscosity of liquid μ (mu), mass density ρ (rho), and pipe diameter (D). The relationship between μ, ρ, and D has the same dimension as velocity. The equation of the Reynolds number can be seen in equation 6.

$$Re = \frac{\rho dv}{\mu} \quad (6)$$

11
 Where Re is Reynold's number, v is flow velocity (m/sec), d is pipe diameter (m), μ is water kinematic viscosity (m²/sec). Based on flow experiments in the pipe, Reynolds determined that for Reynold's numbers below 2000, the flow under these conditions was laminar. The flow will be turbulent if Reynold's number is between the two values $2000 < Re < 4000$ the flow in transition. Reynold's number on the two values above ($Re > 2000$ and $Re < 4000$).

2.5. Head loss

One of the dominant factors to look at in the flow in a pipe is head losses. In general, energy losses can be classified into major head losses due to friction with pipe walls and minor head losses due to joints, bends, valves, and other accessories [7].

Head loss due to friction with pipe walls in uniform flow can be calculated by using Darcy-Weisbach's equation as shown in equation 7.

$$9 \quad hf = f \frac{L v^2}{D 2g} \quad (7)$$

where hf is lost height due to friction (m), f is friction factor, L is pipe length (m), v is the average velocity (m/sec), D is pipe diameter (m), g is gravity acceleration (m/d²). A value for the friction factor gave by [8]. The equation of the friction factor can be seen in equation 8.

$$f (Re \text{ laminar}) = \frac{64}{Re}, Re < 2100 \quad (8)$$

$$f (Re \text{ turbulent with smooth walls}) = \frac{0.316}{Re^{0.25}}, 4000 < Re < 10^5 \quad (9)$$

$$8 \quad f (no \text{ depends on } Re) = f = \frac{1}{(1.74 - 2 \log(\frac{2e}{D}))^2} \quad (10)$$

8
 Losses that occur due to bends, elbows, joints, valves are called minor losses, which can be calculated by the equation (11).

$$hc = kb \frac{(v1-v2)^2}{2g} \quad (11)$$

hc is head loss (m), v is flow velocity (m/s), kb is coefficient of bend losses, g is gravity acceleration (m/d²).

14 3. Research method

3.1. Types of research

The research is experimental research conducted in the laboratory. To obtain research data, the data source comes from primary data, namely data obtained directly from physical model simulations and secondary data obtained from literature and existing research results, both those that have been carried out in the laboratory or other relevant places with the research of head loss in pipes.

3.2. Sample and equipment

The characteristics of fluid samples used in research were 20 density (ρ) 1,000 kg/m³, kinematic viscosity (ν) 0.804×10^{-6} m²/sec, dynamic viscosity (μ) 0.801×10^{-3} Nd/m² (viscosity value) 8, 5.10-7 m²/sec, fatty oil 0 mg/L, and 13 specific gravity (γ) 1.0355 gr/cm³, temperature 29.50C. The variation of rate/discharge used is 0.5 liter/sec, 2.5 liter/sec, 3 liter/sec and 4 liter/sec.

The design of the main test equipment is a pipeline of 600 cm long and 120 cm wide. The pipeline uses acrylic pipes with a diameter of 64 mm, head (z) 500 cm, with several connections, bends, and valves. The series of test equipment, flow direction, and measurement point can be seen in figure 1.

The design of test equipment in figure 1 shows a rectangular design consisting of acrylic pipes, joints, bends, and valves. This line is equipped with a lower and upper reservoir as a reservoir for water samples, a table as a testing device, a water pump machine that regulates the water supply from the lower to the upper reservoir while the upper reservoir enters the test pipe using gravity, a manometer to

measure the pressure level and pitot tubes to measure the flow velocity in pipes installed at several measurement points.

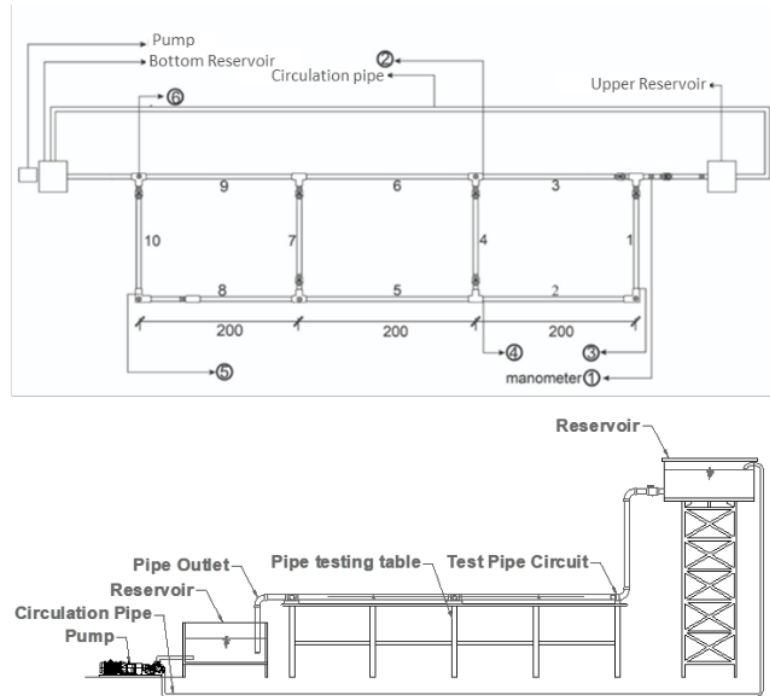


Figure 1. The series of test equipment, flow direction, and measurement point

3.3. The implementation of research

The research was conducted at the Hydraulics Laboratory of the ¹³ Department of Civil Engineering, Faculty of Engineering, Hasanuddin University, Makassar. Preparation of a series of pipes as testing equipment as shown in Figure 1. The first testing by taking the flow rate (Q), adjusting the flow valve opening before the water enters the upper reservoir. This valve is intended to get the variation of rate (Q) to be used. Turn on the pump to supply water from the lower to the upper reservoir and from the upper reservoir, it will flow gravitationally to the test pipe and end to the lower reservoir. The water flow will continue to circulate until the water in the test pipe becomes constant or stable. Measure the flow rate (Q) at the outlet of the test pipe by accumulating water for some time. Read the indicated values for the pressure height (h) on the manometer attached, the velocity (v) on the pitot tube, and the water level (y) at the measurement point in the pipeline. Repeat the procedure for each rate change (Q).

4. Result and discussion

The data collection in the pipeline is divided into 2 (two) segments, namely the direction of flow from the height of the falling water or head 1800 in straight (measurement points 1, 2, and 6) and bending 900 (measurement points 1, 3, 4, 5 and 6). The measurement point can be seen in Figure 1 (a) the measurement result of flow rate (Q), the measurement of water level (y), the measurement of pressure height (h) and flow velocity (v) can be seen in table 1.

Table 1. Measurement and calculation of v , h , Re , H_f , H_c and HL on Q

16 (15/s)	TP	V (m/s)	h (m)	Re	f	H _f (m/s)	H _c (m/s)	HL (m/s)
Q1	1	2,37	0,34	188.895	0,0151	0,01	0,12	0,14
	2	1,91	0,10	152.355	0,0159	0,09	0,08	0,17
	3	1,74	0,25	138.656	0,0163	0,05	0,07	0,11
	4	1,71	0,16	136.170	0,0164	0,08	0,06	0,14
	5	1,84	0,13	146.113	0,0161	0,17	0,07	0,24
	6	1,42	0,09	113.431	0,0172	0,11	0,04	0,15
Q2	1	2,22	0,33	176.980	0,0154	0,01	0,11	0,12
	2	1,79	0,09	142.803	0,0163	0,08	0,07	0,15
	3	1,66	0,20	132.376	0,0166	0,04	0,06	0,10
	4	1,57	0,12	125.293	0,0168	0,07	0,05	0,12
	5	1,66	0,09	132.425	0,0166	0,15	0,06	0,21
	6	1,35	0,09	107.356	0,0172	0,16	0,04	0,20
Q3	1	1,46	0,105	115.922	0,0171	0,01	0,01	0,05
	2	1,04	0,053	82.798	0,0186	0,03	0,03	0,02
	3	1,03	0,026	81.818	0,0187	0,02	0,02	0,02
	4	0,97	0,014	76.968	0,0189	0,03	0,03	0,02
	5	1,10	0,010	87.750	0,0183	0,07	0,07	0,03
	6	1,04	0,011	83.172	0,0186	0,10	0,10	0,02
Q4	1	0,54	0,03	43.161	0,0219	0,0010	0,0063	0,0073
	2	0,34	0,01	27.297	0,0246	0,0046	0,0025	0,0071
	3	0,44	0,01	35.241	0,0231	0,0043	0,0042	0,0085
	4	0,44	0,01	35.241	0,0231	0,0072	0,0042	0,0135
	5	0,37	0,01	29.484	0,0241	0,0106	0,0029	0,0135
	6	0,31	0,01	24.919	0,0252	0,0122	0,0021	0,0143

4.1. Distribution of flow velocity and pressure height

The measurement of flow velocity (v) at several measurement points can be seen in Figure 1. Flow velocity (v) is influenced by the flow rate (Q) and the pipe section area (A). The distribution of flow velocity (v) with the variation of the rate at the measurement point can be seen in figure 2.

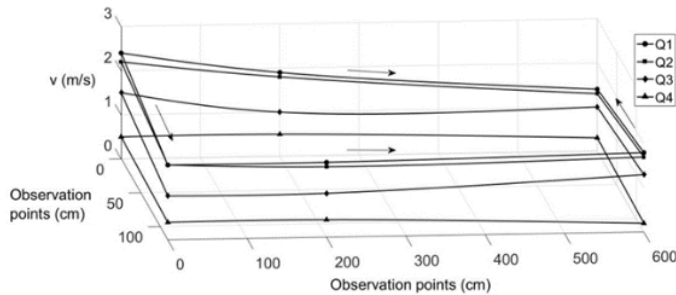


Figure 2. Graph of flow velocity distribution at the observation point

Figure 1 shows the distribution of flow velocity (v) at each measurement point with variations of Q1 0.004 m³/s, Q2 0.0035 m³/s, Q3 0.002 m³/s, and Q4 0.0005 m³/s. At the beginning of the flow, the largest flow velocity (v) is TP 1 followed by TP straight pipe flow and bend pipe flow. In the bend pipe flow, TP 3 is at a distance of 1.20 m from TP1 then bend 90°, the direction of flow changes to a straight line along 6.0 m, at TP 4 at a distance of 2.0 m in the straight direction the flow velocity (v) decreases, and after passing through 90° bend, the velocity of TP5 increases due to the flow passes through the

bend making momentary turbulence which then decreases again at TP 6 at a flow distance of 1.20 m. This situation also applies to the rate of Q2, Q3, and Q4. The flow velocity of the straight pipe at TP2 at a distance of 2.0 m and TP6 at a distance of 4.0 m decreased along with the measurement point until at the end of the flow. It can be concluded that the flow velocity (v) will decrease along the pipe until it reaches the end of the flow. The flow velocity (v) in straight pipe flow is greater because the transportation time (t) reaches the end of the flow is faster. The flow velocity (v) in the bend pipe, the transportation time (t) reaches the end of the flow is longer because when entering the bend area there will be a slowdown in the flow, after passing the bend the flow becomes turbulent for a moment with an insignificant increase in velocity. This phenomenon can be seen in the velocity at TP2 in straight flow and TP3 and TP4 in bend flow.

The measurement point and distance of the pressure height (h) are similar to the flow velocity (v). The pressure height (h) is influenced by the water falling height (z), the flow rate (Q), and the outer section (A). The distribution of pressure height (h) at the measurement point can be seen in figure 3.

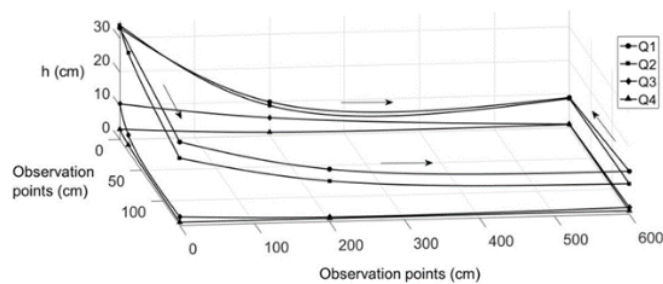


Figure 3. Graph of pressure height distribution at the observation point

Figure 3 shows the distribution of pressure height (h) at each measurement point (TP) and the variation of Q1 0.004 m³/s, Q2 0.0035 m³/s, Q3 0.002 m³/s and Q4 0.0005 m³/s. The value of the pressure height (h) also follows the flow velocity distribution pattern (table 1), except in TP3 in bend flow. This is due to entering the bend, the flow velocity (v) decreases, the pressure height (h) increase. At the beginning of the flow, the pressure height (h) is also TP1 in the direction of the bend pipe flow. The higher of flow rate (Q), the higher of flow pressure (h).

10. Relationship of flow rate, Reynold's number, friction coefficient, and head loss

19 Reynold's number is a dimensionless number that indicates the type of flow. It is influenced by flow velocity (v), pipe diameter (d), and kinematic viscosity (ν). The relationship of flow rate (Q) with the Reynold's (Re) number and the relationship between Re and f can be seen in figure 4. The friction coefficient (f) is influenced by the Reynold's (Re) number. The larger of Reynold's (Re) number, the smaller of f value.

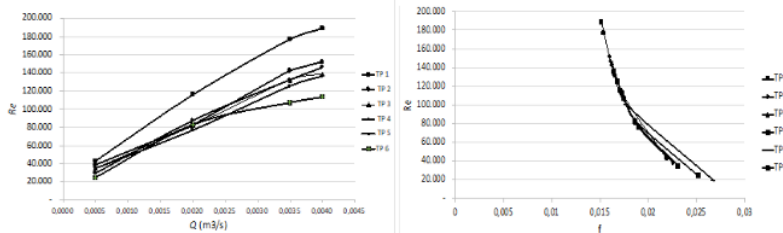
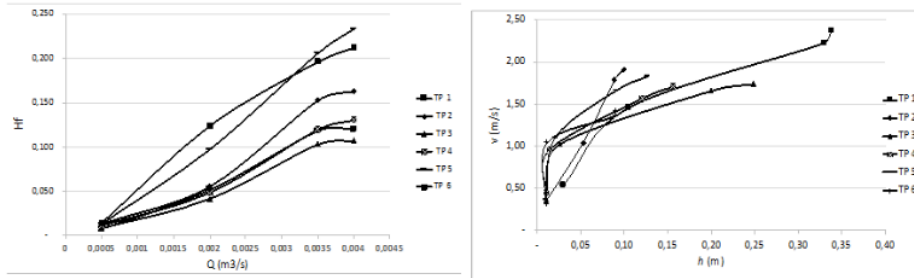


Figure 4. Relationship of discharge/rate with Reynold's number, and the friction coefficient with Reynold's number

Figure 4 shows the relationship between the discharge/rate (Q) and Reynold's (Re) number. As result, the type of flow for each rate (Q) and measurement point (TP) shows turbulent flow, namely $Re > 4000$. The more of rate (Q), the greater of Reynold's number. The largest Re is at TP1. The greater rate (Q), the greater velocity (v) and Reynold's (Re) number [8]. The relationship between rate with head loss and pressure height with velocity can be seen in figure 5.



18
Figure 5. Relationship between rate with head loss and pressure height with velocity

Figure 5 shows the relationship between rate (Q) and head loss (hf). The higher of flow rate (Q) which is followed by an increase in velocity, the greater of head loss. The largest head loss is in the flow in the bend pipe, this is due to increased flow turbulence. In the research of Zainuddin et al stated that the bend angle causes a change in head loss, the greater of bend angle, the greater of head loss, the largest head loss is at a 90° bend. Mahmudin stated that the largest pressure decrease at a 90° bend, it increases with increasing rate.

Figure 5 at the right shows the relationship of pressure height (h) with flow rate (v). The pressure height (h) of flow decreases along the pipe. Sarjito et al. stated that the increase in pressure is influenced by an increase in flow rate (Q), an increase in pressure occurs when passing a 90° bend due to flow slowdown.

17 Conclusions

Based on the results of the analysis, it can be concluded that:

- 1) An increase in flow rate (Q) followed by an increase in flow velocity (v) will increase the Reynold's (Re) number, therefore the head loss in the pipeline will increase. The increase in Reynold's (Re) number influenced by flow velocity will decrease the value of the friction coefficient. The larger of Reynold's number, the smaller the friction coefficient.
- 2) The structure or geometric of the line also influences the flow pattern. In straight pipe flow, the flow velocity is large but the pressure height is small compared to the bend pipe flow where the flow velocity is small, but the pressure height is larger.model.

Acknowledgment

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