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Research Article

Theoretical Investigation of The Major and Minor Losses in Pipes and Fittings

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ABSTRACT

The present study aims to investigate major pressure losses in pipes and minor losses in certain pipe fittings, such as sudden expansion. Initially, the relationships for calculating major and minor losses were derived by applying Bernoulli's equation to the studied components. Flow velocity, pipe diameter, and pipe length effects on major losses were examined. Additionally, the impact of velocity on minor losses in sudden expansion was analysed. The results demonstrated that major losses, represented by friction, significantly vary with changes in flow velocity, pipe diameter, and pipe length. It was found that increasing the pipe diameter by 200% leads to a 6% reduction in major losses. Moreover, increasing the length and velocity results in proportional increases in major losses. Regarding minor losses, the findings indicated that these losses in sudden expansion increase by a factor of six with the increase in velocity.

1. INTRODUCTION

Fluids are predominantly transported through pipes, with circular cross-sections most commonly utilised due to their structural and hydraulic efficiency. Circular pipes are extensively employed in water treatment plants and chemical processing facilities, where they are constructed from various metallic materials to meet the specific requirements of diverse applications. These pipes are available in various sizes to accommodate different flow rates and operational conditions [1-3].

Water piping systems are often found in everyday life, from households, schools, offices, hotels, and industries. Proper piping installation will reduce flow losses that occur in the piping system. The flow loss that occurs in the piping system is directly proportional to the energy loss that occurs. Head losses are the loss of mechanical energy in the mass of fluid. The unit head loss is a unit of length equivalent to one unit of energy required to move one unit of mass of fluid as high as one unit of length accordingly. Head losses are divided into two parts, namely major losses and minor losses; major losses are flow losses caused by friction between the fluid and a straight pipe wall which has a fixed cross-sectional area, and minor losses are losses in fluid flow inside pipes caused by the cross-sectional area of the flow, entrance, fittings, and so on [4-6].

The study and analysis of pressure losses in piping systems are critical aspects of fluid transport engineering. Pressure losses, often caused by friction, turbulence, and flow resistance, influence pump operations' energy consumption and efficiency. Understanding these losses allows engineers to optimise system performance, minimise energy expenditure, and prolong the lifespan of equipment. Strategies to reduce pressure losses include selecting appropriate pipe materials, optimising pipe diameters, and implementing advanced fluid dynamics principles during system design [7-11].

This scientific research aims to analyse and quantify the primary and secondary pressure losses in pipe systems, emphasising the impacts of flow velocity, pipe diameter, and pipe length. The research seeks to establish theoretical correlations for these losses via Bernoulli's equation and to analyse the impact of characteristics such as pipe diameters and flow dynamics on energy efficiency in fluid transport systems. The research also examines the effects of abrupt expansion and contraction on minor losses, aiding in enhancing and optimising pipe systems for energy saving.

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2. THEORETICAL RELATIONS

2.1 Major Losses

They are the losses resulting from the fluid's friction with the tube's walls and are calculated by the Darcy-Weisback equation [12-13]. Consider a segment between 1 and 2; the distance L is shown in Figure (1).

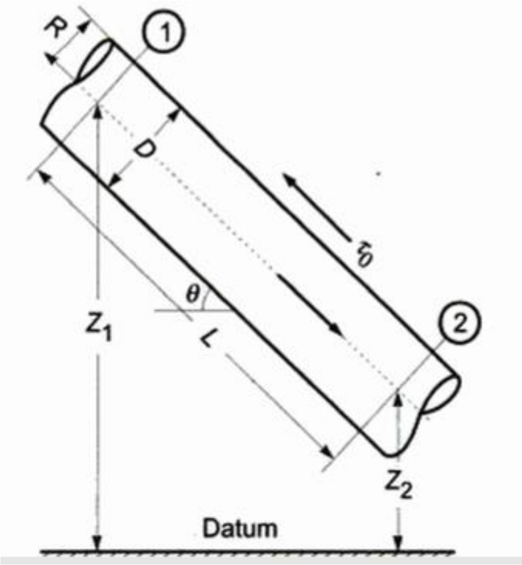

Fig. 1. A section of a pipe.

Applying the Bernoulli equation between points 1 and 2 yields:

$$\frac{P_1}{\gamma} + Z_1 + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + Z_2 + \frac{V_2^2}{2g} + h_f \tag{1}$$

Where P is pressure (Pa), Z is the elevation (m), V is the velocity (m/s), g is the gravitational acceleration (m/s^2), γ is the specific weight of the fluid (N/m^3) and h_f is the major head loss (m).

Since the flow is uniform, then $V = V_1 = V_2$ (2)

Substituting eq (2) in (1) yields

$$h_f = (\frac{P_1}{\gamma} + Z_1 + \frac{V^2}{2g}) - (\frac{P_2}{\gamma} + Z_2 + \frac{V^2}{2g}) \tag{3}$$

$$h_f = -\Delta(\frac{P}{\gamma} + Z) \tag{4}$$

Applying the forces balance between 1 and 2 gives

$$P_1\frac{\pi D^2}{4} - P_2\frac{\pi D^2}{4} + \gamma(\pi R^2)Lsin\theta - \tau_0 2\pi RL = 0 \tag{5}$$

Where D is the pipe diameter (m), R is the pipe radius (m), L is the section length (m), θ is the inclination angle (Degree), and τ_0 is the shear stress at the wall (Pa).

But $Lsin\theta = Z_{1\_}Z_2$ then

$$P_1\frac{\pi D^2}{4} - P_2\frac{\pi D^2}{4} + \gamma\pi R^2(Z_{1\_}Z_2) - \tau_0 2\pi RL = 0 \tag{6}$$

Dividing by $\frac{\pi D^2}{4}$ yields

$$P_1 - P_2 + \frac{4}{\pi D^2}\gamma\pi R^2(Z_{1-}Z_2) - \frac{8}{\pi D^2}\tau_0\pi RL = 0 \tag{7}$$

$$\left(\frac{P_1}{\gamma} + Z_1\right) - \left(\frac{P_2}{\gamma} + Z_2\right) = \frac{2\tau_0 L}{\gamma R} \tag{8}$$

Plugging eq (8) into eq (3) yields

$$h_f = \frac{2\tau_0 L}{\gamma R} = \frac{4\tau_0 L}{\gamma D} \tag{9}$$

τ_0 can be expressed as:

$$\tau_0 = \frac{f}{8}\rho V^2 \tag{10}$$

Where f is Darcy-Weisbach friction factor

$$h_f = 2\,\frac{f}{8}\rho V^2\,\frac{4L}{\gamma D} \tag{11}$$

$$h_f = f\,\frac{LV^2}{2gD} \tag{12}$$

This equation is known as the Darcy-Weisbach equation and is valid for laminar and turbulent flow. In laminar flow, the Hagen-Poiseuille equation [14] becomes

$$h_f = \frac{32\mu VL}{\gamma D^2} \tag{13}$$

From eq (13) and (12) f becomes

$$f = \frac{64}{\rho VD/\mu} = \frac{64}{Re} \tag{14}$$

Where μ is the viscosity of the fluid (Pa.s), ρ is the fluid density (kg/m^3) and Re is Reynolds number.

2.1 Minor Losses in Sudden Expansion

It is the losses resulting from liquid flow in an expanded pipe [15], by considering a flow segment between points 1 and 2 during a sudden expansion and applying Bernoulli's equation.

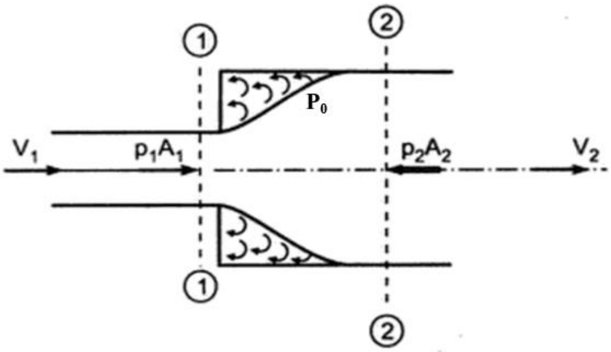

Fig. 2. A sudden expansion

$$\frac{P_1}{\gamma}+Z_1+\frac{V_1^2}{2g}=\frac{P_2}{\gamma}+Z_2+\frac{V_2^2}{2g}+h_{se} \tag{15}$$

Where h_{se} is the minor loss due to the sudden expansion. By ignoring the difference in elevation, $Z_1=Z_2$ yields:

$$h_{se}=\left(\frac{P_1}{\gamma}-\frac{P_2}{\gamma}\right)+\left(\frac{V_1^2}{2g}-\frac{V_2^2}{2g}\right) \tag{16}$$

Applying the momentum equation, which states that the net forces are equal to the change in momentum,

$$\mathrm{P_1A_1}-P_2A_2+P_0(A_2-A_1)=m(V_2-V_1) \tag{17}$$

From practical experiments, it was found that $\mathrm{P_0}=\mathrm{P_1}$

$$\mathrm{P_1A_1}-P_2A_2+P_1(A_2-A_1)=\rho Q(V_2-V_1) \tag{18}$$

$$\mathrm{P_1A_1}-P_2A_2+P_1A_2-P_1A_1=\rho Q(V_2-V_1) \tag{19}$$

$$(P_1-P_2)A_2=\rho Q(V_2-V_1) \tag{20}$$

$$(P_1-P_2)=\frac{\rho Q}{A_2}(V_2-V_1) \tag{21}$$

$$(P_1-P_2)=\rho V_2(V_2-V_1) \tag{22}$$

By dividing both sides by γ we get

$$\frac{(P_1-P_2)}{\gamma}=\frac{V_2}{g}(V_2-V_1) \tag{23}$$

$$\frac{(P_1-P_2)}{\gamma}=\frac{V_2^2-V_2V_1}{g} \tag{24}$$

$$\frac{(P_1-P_2)}{\gamma}=\frac{2V_2^2-2V_2V_1}{2g} \tag{25}$$

And by substituting the equation (25) into the equation (16) yields:

$$h_{se}=\frac{2V_2^2-2V_2V_1}{2g}+\frac{V_1^2}{2g}-\frac{V_2^2}{2g} \tag{26}$$

$$h_{se}=\frac{V_2^2-2V_2V_1+V_2^2}{2g} \tag{27}$$

$$h_{se}=\frac{(V_2-V_1)^2}{2g} \tag{28}$$

3. RESULTS

The effect of pipe diameter on the velocity and major losses has been studied. The effect of pipe length and velocity on major losses was also studied. While for secondary losses, the effect of velocity on losses resulting from sudden expansion was examined. The flow was assumed to be laminar.

3.1 Effect of Diameter on Velocity and Major Losses

Figure (3) represents the effect of increasing the diameter of the pipe on the flow velocity by fixing the volumetric discharge rate. It is noted that the relationship is inverse between the velocity and the diameter; when the diameter of the pipe increases, the velocity decreases with the constant flow, according to the principle of mass conservation.

Figure (4) represents the effect of increasing the diameter of the pipe on the major losses (friction losses). The increase in the diameter of the pipe only leads to an increase in friction losses due to the increase in the wet circumference of the pipe.

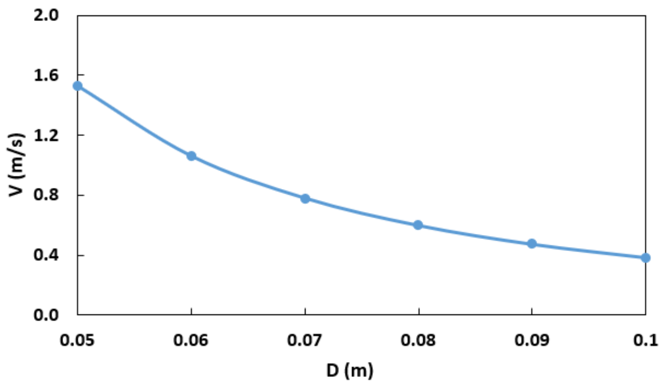

Fig. 3. Effect of diameter on velocity (Q=3 L/s).

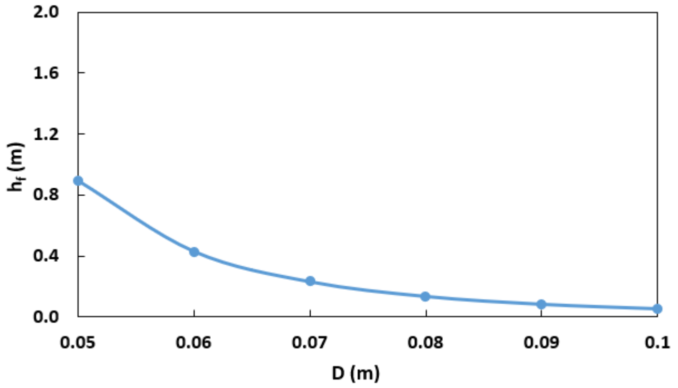

Fig. 3. Effect of diameter on major loss (Q=3 L/s).

3.2 Effect of Length on Major Loss

Figure (4) represents the effect of increasing the length of the pipe on the major loss (friction loss). It is noted that the change of losses with length is a linear change, and the increase in the length of the pipe leads to an increase in friction losses due to the increase in the contact area of the pipe with the fluid.

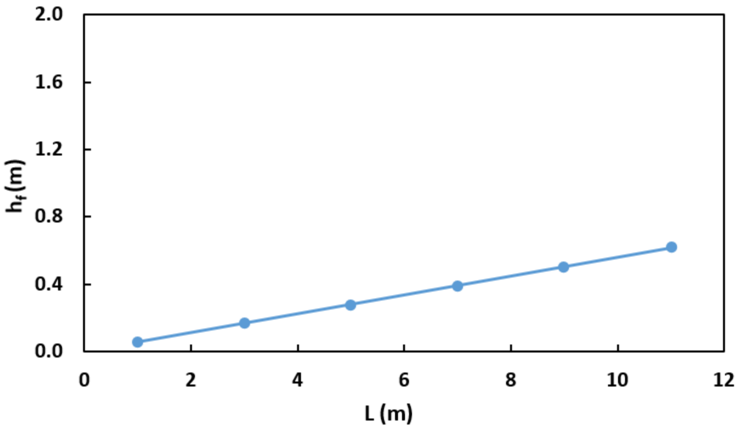

Fig. 4. Effect of length on major loss (Q=3 L/s).

3.3 Effect of Velocity on Major Loss

Friction losses change linearly with flow velocity, as in Figure (5), due to the increase in the amount of fluid in contact with the pipe wall.

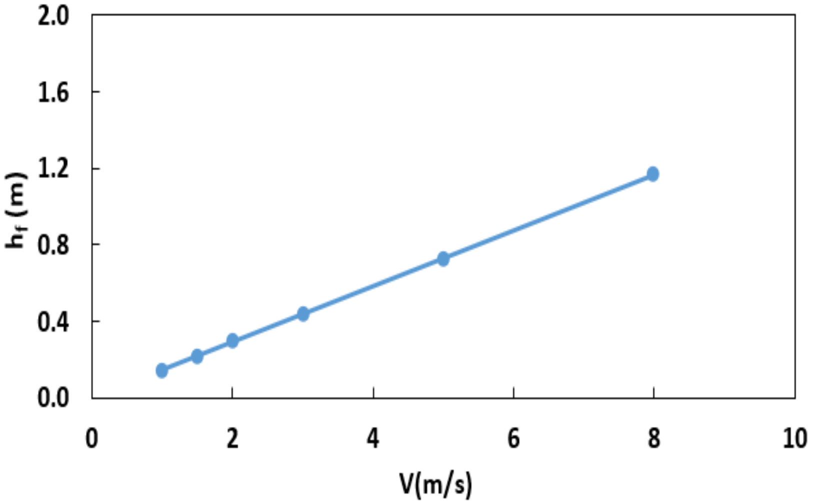

Fig. 5. Effect of velocity on major loss.

3.4 Effect of Velocity on Minor Loss

Figure (6) represents the effect of flow velocity in the sudden expansion on the minor losses in the sudden expansion connection. It is noted that the relationship between them is proportional.

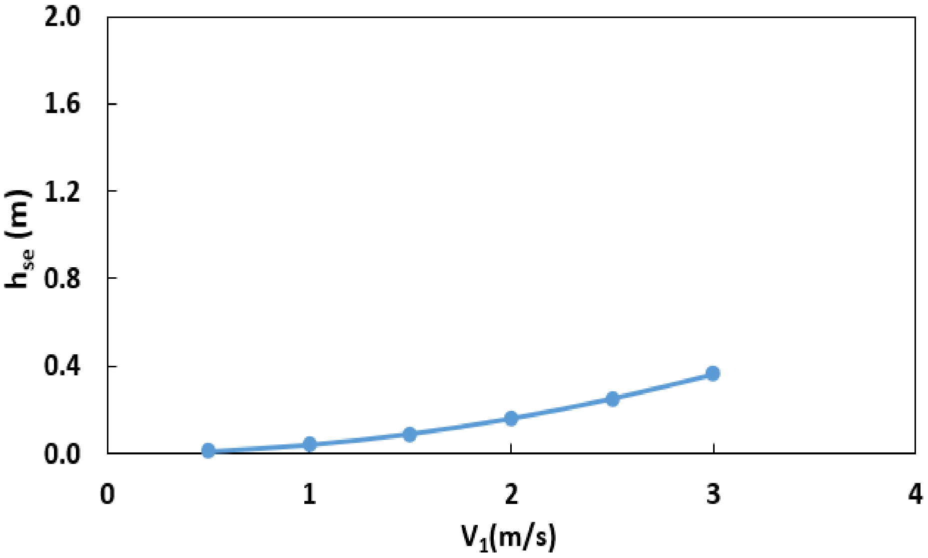

Fig. 6. Effect of velocity on minor loss in sudden expansion.

4. CONCLUSIONS

The present work studies the major losses of pressure heads in pipes and minor losses of pressure heads in sudden expansion theoretically. The effect of tube diameter, flow velocity and length on the major losses is examined. Also, the effect of pipe diameter on the velocity is studied. Finally, the effect of velocity on the minor losses in the sudden expansion is examined. The main results can be summarised as:

- Friction losses increase with the increase in pipe diameter.
- Friction losses increase with increasing the velocity and pipe length.
- Minor losses increase with increasing velocity.

Conflicts Of Interest

The author's paper explicitly states that there are no conflicts of interest to be disclosed.

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