Analysis of energy losses in smooth pipes

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Abstract. Pipe is a closed conduit, usually of circular section, which is used for carrying fluids under pressure. The pipe running partially full, in such a case atmospheric pressure exists inside the pipe, also behaves like an open channel. In general, energy or head losses on pipe consisted of major energy losses due to friction and minor energy losses due to sudden enlargement of pipe, sudden contraction of pipe, bend in pipe, an obstruction in pipe, pipe fittings etc. The main purpose from this research is to analyse energy losses in smooth pipes. There are several steps in analysing such as calculating Reynolds Number (Re) in order to determine flow type, calculating friction factor by using several formulas, and calculating roughness value (k) on smooth pipe with different various scenarios. The experimental study was performed at Hydraulics and Fluid Mechanics Laboratory to process the analysis. The results indicated that the flow type is turbulent when Reynolds Number (Re) is more than 4000. The turbulent flow is characterized by random and irregular movement of fluid particles. The other result also shown that roughness value (k) in smooth pipe is inverse proportion to Reynolds Number.

1. Introduction
Pipe is a closed conduit, usually of circular section, which is used for carrying fluids under pressure. The pipe running partially full, in such a case atmospheric pressure exists inside the pipe, also behaves like an open channel [1,2]. The knowledge of pipe is based on the universal principles of fluid flow. When a real (viscous) fluid flows through a pipe, part of its energy is spent through maintaining the flow. Energy losses in pipes used for the transportation of fluids are essentially due to friction, as well as to the diverse singularities encountered. These losses are usually converted into head reductions in the direction of the flow [3,4]. Due to internal friction and turbulence, this energy is converted into thermal energy. Such a conversion leads to the expression of the energy loss in terms of the fluid height termed as the head loss and usually classified into two categories. Essentially due to friction, the first type is called linear or major head loss [5]. It is present throughout the length of the pipe. The second category called minor or singular head loss is due to the minor appurtenances and accessories present in a pipe network [6]. The appurtenance encountered by the fluid flow which is a sudden or gradual change of the boundaries results in a change in magnitude, direction or distribution of the velocity of the flow. This classification into major and minor head losses is rather relative. For a pipeline of small length having many minor appurtenances, the total minor head loss can be greater than the frictional head loss [7]. The main purpose from this research is to analyze energy losses in smooth pipes. In general, energy or head losses on pipe consisted of major energy losses due to friction and minor energy losses due to sudden enlargement of pipe, sudden contraction of pipe, bend in pipe, an obstruction in pipe, pipe fittings etc.
1.1. Head in pipes
Some studies were performed in order to investigate diverse types of head losses. When water flows in a pipe, it experiences some resistance to its motion, due to which its velocity and ultimately the head of water available is reduced. This loss of energy is classified as follows: (a) major or primary energy losses due to friction and (b) minor or secondary energy losses due to sudden enlargement, sudden contraction, obstruction in pipe, at the entrance to pipe, at the exit of a pipe, bend and in various pipe fittings, etc. [8,9].

1.2. Darcy-Weisbach formula
The loss of head or energy in pipes due to friction is calculated from Darcy-Weisbach formula which is given by equation 1.

\[ hf = \frac{f}{L} \frac{V^2}{D} \frac{1}{2g} \]  

(1)

Where

- \( H_f \) = Loss of head due to friction (m)
- \( f \) = Friction factor
- \( L \) = Length of the pipe (m)
- \( V \) = Mean velocity of flow (m/sec)
- \( D \) = Diameter of the pipe (m)

Or it can be translating into equation 2.

\[ f = 0.0055 \left( 1 + \left[ \frac{20000K}{D} + \frac{10^6}{Re} \right]^{\frac{1}{3}} \right) \]  

(2)

Other previous research on smooth pipes has been done by Blasius (1908) and the equation is given by equation 3 and 4.

\[ f = \frac{0.3164}{Re^{0.25}} \quad \text{for} \quad 4 \times 10^4 < Re < 10^5 \]  

(3)
Where

\[ f = \text{Friction factor} \]
\[ \text{Re} = \text{Reynolds Number} \]

Friction factor can be calculated by Karman-Nikuradse formula

\[ f = 0.184 \text{Re}^{-0.20} \]  \hspace{1cm} (4)

For equation 4, applies to $3 \times 10^3 < \text{Re} < 10^6$

**Figure 2.** Head of energy in changed pipe.

1.3. **Classification of flows in pipe**

A flow can be laminar, turbulent or transitional in nature. This becomes a very important classification of flows and is brought out vividly by the experiment conducted by Osborne Reynolds (1842 - 1912). Reynolds Numbers are dimensionless number that plays a prominent role in foreseeing the patterns in a fluid’s behavior. The Reynolds Number, referred to as Re, is used to determine whether the fluid flow is laminar or turbulent. Under most practical conditions, the flow in a circular pipe is laminar for Re $2000$, turbulent for Re $4000$, and transitional in between [10,11].

2. **Research method**

The experimental study was performed at Hydraulics and Fluid Mechanics Laboratory, Maranatha Christian University, to process the analysis. There are several steps in analyzing such as calculating Reynolds Number (Re) in order to determine flow type, calculating friction factor by using several formulas, and calculating roughness value (k) on smooth pipe with different various scenarios. Moody Diagram that can be used to validate the estimation of friction factor. The Moody friction factor (or f), is also used in the Darcy Weisbach formula for major loss in pipes. If the flow is transient, $2000 < \text{Re} < 4000$, the flow varies between laminar and turbulent flow and the friction coefficient is not possible to determine. The friction factor can usually be interpolated between the laminar value at $\text{Re} = 2000$ and the turbulent value at $\text{Re} = 4000$. The Moody Diagram can be seen on figure 3.
However, Moody Diagram only suitable for rough pipes which have higher value of roughness than smooth pipes.

3. Results and discussion
Several analyses have been carried out to investigate the type of flows in selected pipes. The average discharge has calculated by using sharp-crest weir measurement and the results is 4.28 cm$^3$/sec. The calculation of head energy in pipe can be seen on table 1. Based on the results, smooth pipe with smaller diameter of pipe give the higher head energy (H). The higher height of pipe (T$_{pipe}$) the higher head energy (H).

| Position | T$_{pipe}$ | z   | h$_a$ | H  |
|----------|-----------|-----|-------|----|
| Upper    | 175 cm    | 173 cm | 42 cm | 46 cm |
| Piezo 1  | 175 cm    | 173 cm | 30 cm | 34 cm |
| Piezo 2  | 173 cm    | 171 cm | 29 cm | 33 cm |
| Piezo 3  | 173 cm    | 170 cm | 28 cm | 28 cm |
| Piezo 4  | 171 cm    | 167 cm | 33 cm | 33 cm |
| Piezo 5  | 132 cm    | 128 cm | 72 cm | 72 cm |
| Piezo 6  | 128 cm    | 125 cm | 75 cm | 75 cm |
| Piezo 7  | 158 cm    | 155 cm | 46 cm | 46 cm |
| Piezo 8  | 159 cm    | 155 cm | 45 cm | 45 cm |
| Piezo 9  | 158 cm    | 154 cm | 43 cm | 43 cm |
| Piezo 10 | 157 cm    | 154 cm | 45 cm | 46 cm |
| Piezo 11 | 155 cm    | 154 cm | 27 cm | 38 cm |
| Piezo 12 | 155 cm    | 154 cm | 9 cm  | 21 cm |
Table 2. Calculation of head energy in smooth pipe.

| Section of pipe | Velocity (cm/sec) | Diameter Ø (cm) | Re       | Flow type   |
|-----------------|-------------------|-----------------|----------|-------------|
| 1               | 84.54             | 2.54            | 23940    | Turbulent   |
| 2               | 13.74             | 6.3             | 9652     | Turbulent   |
| 3               | 13.74             | 6.3             | 9652     | Turbulent   |
| 4               | 13.74             | 6.3             | 9652     | Turbulent   |
| 5               | 37.77             | 3.8             | 16002    | Turbulent   |
| 6               | 151.09            | 1.9             | 32004    | Turbulent   |

Table 3. Calculation of friction factor.

| Segmen | Darcy Weisbach | Blasius $4.10^3 < Re < 10^5$ | Nikuradse |
|--------|----------------|-------------------------------|-----------|
| 1      | 0.0238         | 0.0254                        | 0.0059    |
| 2,3,4  | 0.0317         | 0.0319                        | 0.0071    |
| 5      | 0.0282         | 0.0281                        | 0.0063    |
| 6      | 0.0253         | 0.0236                        | 0.0055    |

4. Conclusions
The results indicated that the flow type is turbulent when Reynolds Number (Re) is more than 4000. The turbulent flow is characterized by random and irregular movement of fluid particles. Friction factor from Blasius formula is the most appropriate to define roughness value in smooth pipe. The other result also shown that roughness value (k) by using Moody Diagram in smooth pipe is inverse proportion to Reynolds Number. The experimental results show that the head losses in smooth pipe are greater than those computed by the different empirical formulas used. It is happened because the fact that the roughness coefficient (k) which is the most important parameter might have not been suitably predicted. Thus, neglecting the possible presence of deposits which generally tends to increase the roughness of pipe walls and consequently the head loss. More complexity is happened when head losses in smooth pipe through singularities are investigated. The intermediate region downstream of any appurtenance is a mixture of friction and turbulence phenomena, and it is difficult to separate the effects of each one. Further research should be directed towards defining precise minor coefficients by taking into account all the factors involved in such head losses. It is recommended to investigate further research with other pipe’s types.

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References
[1] Kodoatie R J 2001 Hidrolika Terapan Aliran pada Saluran Terbuka dan Pipa (Yogyakarta, Semarang: ANDI)
[2] Triatmodjo B 1993 Hidraulika I (Yogyakarta: Badan Penerbit Beta Offset)
[3] Triatmodjo B 1996 Hidraulika II (Yogyakarta: Badan Penerbit Beta Offset)
[4] Dake J M K 1985 Hidrolika Teknik (Jakarta: Badan Penerbit Erlangga)
[5] Chow V T 1992 Hidrolika Saluran Terbuka (Bandung: Erlangga)
[6] Maryono A 2008 Eko-Hidraulik Pengelolaan Sungai Ramah Lingkungan (Yogyakarta: Gadjah Mada University Press)
[7] Moody L F 1944 Friction Factors for Pipe Flow Trans. American Society of Mechanical Engineers 66 671-684
[8] Williams G S and Hazen A 1933 *Hydraulic tables* 3rd Edition (USA: John Wiley & Sons nc.)
[9] Wood D J 1972 An Explicit Friction Factor Relationship *Civil Engineering, Am. Soc. of Civil Engrs.* 383-390
[10] Lamont P 1969 The Choice of the Pipe Flow Laws for Practical Use *Water and Water Engineering* 55-63
[11] Techo R, Tichner R R and James R E 1965 An Accurate Equation for the Computation of Friction Factor for Smooth Pipes from the Reynolds Number *J. of Applied Mechanics* 32 443