A BRIEF REVIEW OF EXPERIMENTAL FRICTION LOSS STUDIES FOR POLYETYLENE PIPES

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ABSTRACT:

Plastic pipes, especially polyethylene pipes have grown to become one of the frequently utilized material in pipeline systems owing to its advantages of corrosion, biological and chemical resistance over traditional metal pipes. Similar to any other material, design of polyethylene pipeline system requires a comprehensive and detailed friction head loss analysis. There are two main methods on the literature recommended for estimating friction head loss. One is the well-known Darcy–Weisbach equation and the other is an empirical formula known as Hazen–Williams equation. Darcy–Weisbach equation depends on Darcy friction factor and Hazen–Williams equation depends on Hazen–Williams coefficient. To estimate Darcy friction factor, pipe roughness height must be known. In the recent studies, head losses in polyethylene and plastic pipes are commonly estimated by using some constant coefficients for pipe roughness height and Hazen–William formula. However, the experimental studies revealed that these values have a strong dependence on varying pipe diameter and flow regime characterized by Reynolds numbers. Therefore, a single fixed value cannot be used for all ranges of diameters and flow velocity on polyethylene pipelines. In this paper, the authors reviewed the experimental studies for friction loss on polyethylene pipes and recommended some methods to hydraulic design of polyethylene pipeline systems. The results indicated the shortage of experimental studies for plastic pipes, particularly for higher ranges of polyethylene pipe sizes.

1. INTRODUCTION

Polyethylene (PE) pipes have grown to become one of the most extensive usage plastic material on the World for applications of water distribution systems, fresh water supply systems, sea intake systems, petroleum product systems, sustainable energy systems and other demanding applications. A study that published on Pipeline Division Specialty Congress indicate that eight case studies were done for both urban and industrial polyethylene pipeline networks on North America Region and results show that PEs are eco-friendly, earthquake resistant, and corrosion resistant material [1]. In comparison with traditional metal pipe materials, a recent study showed that PE is a better alternative in terms of environmental sustainability [2]. Also, PEs provide a better biological and chemical resistance with comparing the metal pipes. Undoubtedly, PEs will become more important on the future's construction project, especially on pipeline systems.

Friction head loss is a significant engineering factor on hydraulic design of pipeline. Darcy–Weisbach equation and Hazen–Williams equation are used to estimate friction head loss. Darcy-Weisbach equation can be used only if Darcy friction factor is known. Colebrook equation is accepted as the best predictor of Darcy friction factor in the scientific and academic community for all kind of pipe materials on turbulent regime. Several theoretical studies were done by researcher to determine best method for estimating friction losses and factors on plastic and polyethylene pipe systems. Allen [3] investigated the relation between Darcy-Weisbach and Hazen-Williams equation on his study for several pipe materials which is including plastic pipes. Bombardelli and Garcia [4] done an analyze of hydraulic design for large diameter pipes and highlights some comments the use of Hazen-Williams equation on large diameter systems. Taş and Ağıralioğlu [5] analyzed accuracy of different friction loss estimation methods on a long polyethylene pipeline system and results of the study indicated that Colebrook equation is still best predictor of friction factor estimation on long polyethylene systems. Also, Neto and his colleagues [6] done an improvement on Darcy-Weisbach equation named as "PDHLE equation" which is consider the pipe cross-section variations depending on pressure changes on the polyethylene pipe system.

Significant point on here is that all these methods depend on some fixed parameters such as pipe roughness height (e) and Hazen–Williams coefficient (C_{HW}) for each type of pipe material. These values are accepted as constant on calculations of friction loss even if pipe diameter or flow velocity is varying. Determination of pipe roughness (e) is very difficult. It needs a comprehensive analysis and experimental studies especially for fully turbulent regimes when Reynolds Number is large enough. Also, Farshad and Pesacreta [7] indicated that there is a scarce on the literature about the researches on surface roughness height analysis and experiments for new generation pipes.

There are a very limited number of articles may be found on the literature about the friction losses that depend on friction factor and roughness height experiments on plastic and polyethylene pipeline systems. Howell and Hiler [8] installed an experiment system for 13 mm polyethylene pipeline and examine the Hazen-Williams coefficient. Hughes and Jeppson [9] were performed a field measurement on small diameter plastic pipes and propose an experimental value for Hazen-Williams coefficient. Von Bernuth and Wilson [10] measured the experimental data for both PVC and polyethylene pipes in varying diameter of 14 mm to 26 mm and examine the accuracy of Blasius equation for friction factor. Bagarello and his colleagues [11] measured the experimental results for low density polyethylene pipes in varying diameter of 16 mm to 25 mm and examined the accuracy of Blasius equation for friction factor. In addition they examined the temperature effect on friction factor coefficient. Moghazi [12] conducted a laboratory experiment to examine the experimental values of Hazen–Williams coefficient for polyethylene pipes with varying diameters between 13 mm to 22 mm. Study of Moghazi indicates that there are some differences between the experimental values and accepted values for Hazen–Williams coefficient. Yıldırım and Özger [13] used the experimental data of Moghazi [12] and propose a neuro-fuzzy approach to identify a proper value for Hazen-Williams coefficient for polyethylene pipes. Diogo and Vilela [14] performed 4 different experiments on PVC, low density polyethylene and high-density polyethylene pipes. On this study, diameters of pipes varied between 17.35 mm to 110 mm. Based on the experimental results the friction factor and proper roughness values for each pipe materials was examined. Provenzano and his colleagues [15] carried out an experiment on 16 mm lay-flat polyethylene pipe with several wall thickness values to test the effect of varying pressure and flow rates on pipe geometry. Coelho and his colleagues [16] were carried out an experimental installation for 25 mm polyethylene tubing to determining best equation for calculation of head losses.

2. SEMI – THEOROTICAL BASE CALCULATION OF FRICTION HEAD LOSSES

There are several methods to estimate the total friction loss on a pipeline system including polyethylene pipe material methods. But Darcy–Weisbach and Hazen Williams equations are the significance ones on the literature for pipeline and network calculations. These equations can be represented as follows respectively:

$$h_f = f\left(\frac{L}{D}\right)\frac{V^2}{2g} \tag{1}$$

$$V = 0.849\, C_{HW}\, R^{0.63}\, \frac{hf^{0.54}}{L} \tag{2}$$

Where; h_f is total friction head loss, f is Darcy friction factor, L is the length of the pipeline, D is the pipe diameter, V is the flow velocity in the pipeline, g is gravitational acceleration, C_{HW} is Hazen – Williams coefficient and R is hydraulic radius.

2.1. Calculation of Friction Factor

To estimate the friction loss on a pipeline system, friction coefficient for both Darcy – Weisbach and Hazen – Williams must be calculated. Darcy friction factor (f) may be expressed as a function of Reynolds Number (Re) and relative roughness which is the ratio between the pipe surface roughness (e) and pipe diameter (D). Also Hazen–Williams coefficient (C_{HW}) is another coefficient related with the surface roughness on calculations. After rearranging equations 1 and 2, the relation between the Darcy friction factor (f) and Hazen-Williams coefficient (C_{HW}) can be obtained by study of Kamand [17] and it can be expressed as:

$$f = 10.079\, g\, (0.849\, C_{HW})^{-1.852}\, D^{-0.167}\, V^{-0.148} \tag{3}$$

Darcy friction factor directly depends on the Reynolds Number and flow regime. In the range of 4000 – 10^5 Reynolds Number, Blasius equation can be used to estimate friction factor without considering the roughness height of the material. Blasius equation [18] can be expressed as:

$$f = \frac{0.3164}{Re^{0.25}} \tag{4}$$

The determination of friction factor for turbulent flow regime is one of the most significant stage on hydraulic design of pipeline systems. The higher range on turbulent regime on a pipeline, Colebrook equation and various approximations of it can be used to estimate friction factor that depends on the roughness height of the material. Colebrook equation [19] that covers the whole turbulent flow regime (Re = 4000 - 10^8) can be expressed as:

$$\frac{1}{\sqrt{f}} = -2\log\left[\frac{2.51}{Re\sqrt{f}} + \frac{\frac{e}{D}}{3.7}\right] \tag{5}$$

3. EXPERIMENTAL STUDIES ON PLASTIC PIPES

Several experimental studies were performed on the literature for plastic and polyethylene pipes. Experimental results were compared with the friction loss and friction factor calculations methods. Some of these studies are given as chronological order below.

In 1989, Von Bernuth and Wilson [10] were performed an experiment to measure the friction factor results for three small diameter plastic pipes. Experiment was including two commercial PVC pipe system with a nominal diameter of 16 mm and 26 mm. Also, a nominal diameter of 14 mm polyethylene pipe which is used on drip irrigation system. Each pipe system had a length of 30 m. Two differential mercury manometers were used to measure pressure and they were placed 3 m from each end of the pipeline system. The experiments run several times where Reynolds Number less than 10^5 and biggest diameter was 26 mm on the experiment. Author indicates that for Reynolds number less than 10^5 the Blasius equation is an accurate estimating method of Darcy friction factor for small diameter plastic pipes.

In 1995, Bagarello and his colleagues [11] were performed an experimental investigation by using small diameter plastic pipes. On the experiment, three different sizes low-density polyethylene pipes were used with a nominal diameter of 16 (ND16), 20 (ND20) and 25 (ND25) mm. The length of the experiment system was 100 m. Authors added the temperature effect to pipeline system for developing Von Bernuth and Wilson's study [10]. Based on the study, authors indicated that Reynolds number can express the influence of water temperature on flow resistance law for polyethylene pipes.

In 1998, Moghazi [12] conducted a laboratory experiment with different size commonly used polyethylene pipes. Four polyethylene pipes were used on the experiments to determine proper values of C_{HW} experimentally. The sizes of the pipes were 13, 16, 19 and 22 mm. The length of the experiment installation was 25 m. Two digital pressure gauges were used to measure pressure gradients and they were placed each end of the installed pipeline system. The experimental results and the recommended values of C_{HW} were compared on the study. The maximum differences were observed between the 13 mm and 22 mm polyethylene pipes with a ratio of 14 and 27 % respectively.

In 2014, Diogo and Vilela [14] were performed several experiment investigations with using several diameters of PVC, a low-density polyethylene and a high-density polyethylene pipes to measure head losses and friction factors for steady flows on pipes in turbulent flow regime. The first installation was including two old PVC pipes and the internal diameters of the pipes were 17.35 mm and 21.75 mm. The length of the installed pipe system was 2 m. Second experiment installation was performed using a high-density polyethylene pipe and the nominal diameter of the pipe was 63 mm. The length of the installed system was 6.5 m. Third installation was including a low-density polyethylene pipe and the nominal diameter of the pipe was 110 mm. Total length of the installed pipe system was 32.35 m. Last installation was including a flexible PVC pipe and the internal diameters of the pipe was 35 mm. Total length of the installed pipe system was 21.5 m. Experimental test results for 63 mm high-density polyethylene pipe and 110 mm low-density polyethylene pipe can be seen in Figure 1a and Figure 1b. According to experiment results of 63 mm pipe diameter size pipe (see Figure 1a) roughness height can be determined between 0.030 and 0.010 till approximately 10^5 Reynolds number and it can be determined between 0.010 and 0.002 till approximately till 10^6 Reynolds number. Also, results of 110 mm pipe diameter size pipe (see Figure 1b) show that roughness height can be determined approximately 0.050 till 10^5 Reynolds number.

In 2015, Provenzano and his colleagues [15] were done an experimental installation, using nominal diameter of 16 mm lay-flat polyethylene pipes with 6, 8 and 10 mil pipe wall thickness respectively. Mil represents thousand of an inch. The purpose of the study was investigating the how varying pressures and flow rates causes a change on the different wall thickness pipe's geometry. Based on the experimental results, authors indicate that when pressure increases pipe diameter also increases linearly. Therefore, changing pipe geometry characterized by pressure and flow rates must be another consideration on friction loss calculations for polyethylene pipes.

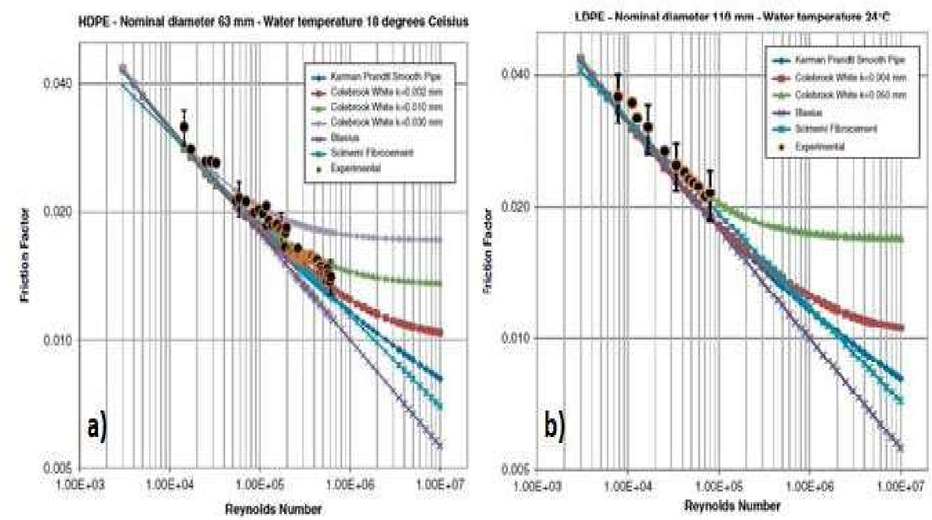

Figure 1: Observed values for a) 63 mm High-density polyethylene pipe b) 110 mm Low-density polyethylene pipe [14]

3. CONCLUSION

Most of the hydraulic estimations for friction head losses and friction factors, recommended fixed values are used for both roughness height (*e*) and Hazen–Williams coefficient (C_{HW}) without considering varying pipe diameters. A brief review of literature was completed in this paper. Based on the experiments, a strong relation between the pipe diameter, flow regime, pressure and friction coefficients was observed. Therefore, a single fixed value of *e* or C_{HW} will not an accurate use for all ranges of pipe diameter and flow regime characterized by Reynolds number. The existing studies were considered only low diameter polyethylene or plastic pipes (the biggest one is 110 mm). Therefore, there is a scarcity on the literature for high diameter as well as high flow rates on the plastic and polyethylene pipes. To determine the pipe roughness height and Hazen–Williams coefficient in high diameter pipes, a comprehensive experiment must be done by using high – sensitivity pressure gauges and flow meters. In the light of experimental implications for high diameter pipes, a new approach can be developed to estimate friction losses.

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