The Eurasia Proceedings of Science, Technology,
Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2019

Volume 7, Pages 357-362

IConTES 2019: International Conference on Technology, Engineering and Science

Evaluation and Correlation of Friction Head Losses in Smooth and Rough Pipes

Abdelkrim HADDAD
Université 8 Mai 1945

Abstract: In order to transport a fluid, the energy losses mainly due to friction have to be overcome. Expressed in fluid height and referred to as head reduction, they are essentially dependent on pipe roughness and fluid low regime, and constitute the basis for the computation of fluid transportation and distribution networks design and analysis. The present paper reviews the diverse relationships that lead to the computation of friction head losses, and compare the results obtained to those of the experimentations carried out on pipes of diverse roughness and fluid flow regimes. The Hazen-Williams and Strickler relationships have been found to be the most appropriate to predicting the friction head losses in smooth and rough pipes respectively. Second-order polynomial correlations of the experimental results are developed for the cases investigated.

Keywords: Head loss, Friction, Fluid flow transportation, Distribution networks

Introduction

Due to internal friction and turbulence, the energy of a flowing fluid is spent through maintaining its movement. It is present throughout the length of the pipes and expressed in terms of height or head loss. Appurtenances and accessories present in a pipe network and usually termed ad minor losses contribute to this loss of energy. However in petroleum and water distribution systems that are constituted of pipelines of considerable length, minor losses are usually found to be insignificant compared to their major counterparts, and may thus be neglected. (Weisbach, 1845) came out with the first relationship that expresses the head loss. (Darcy, 1857) contributed to the application of the derived relationship that has been since known as the Darcy-Weisbach formula. It essentially depends on the relative roughness and the friction coefficient, this latter being a function of the flow regime characterized by the Reynolds number. Several explicit and implicit relationships were since proposed for the friction coefficient. (Moody, 1944) produced the universally known diagram called after him. It allows the determination of the friction coefficient as a function of the Reynolds number and the relative roughness coefficient.

Several other investigators such as (Blasius, 1913), (Colebrook, 1939) and (Ger and Holly, 1976) provided the literature with diverse equations that are of implicit type, thus requiring a try-and-error procedure in order to achieve a solution leading to a value of the friction coefficient. Explicit relationships expressing the friction coefficient for all regimes are available. An interesting review of the diverse formulas is presented by (Lahiouel and Haddad, 2002). As reported by (Powell, 1968) and (Williams, 1970) and as early as 1891, (Manning, 1891) derived such a formula. (Strickler, 1923) suggested a simpler relationship based on a fixed coefficient. (Williams and Hazen, 1933) expressed the head loss as a function of the pipe diameter and length, and the flow rate. They used an empirical coefficient that essentially depends on the pipe material, as described later by (Lamont, 1969). Similar to that of (Williams and Hazen, 1933), (Scobey, 1966) derived a relationship that uses a fixed coefficient. In 1965, Calmon and Lechapt (CEMAGREF, 1983) used three coefficients instead and suggested a relationship that varies with the pipe roughness.

Experimentations were carried out by the author using pipes of various roughness and diameters inside which water was made to flow at different regimes. The linear head losses were measured, and the results obtained were subsequently compared to those achieved by the computations using the six most common pipe flow formula presented.

Theoretical Approach

The main advantage of determining the frictional head losses in pipes lies in finding out the optimal solution that enables their reduction leading to saving energy. Frictional losses are mainly generated by fluid viscosity and flow regime, and may be presented throughout the length of the pipe.

Table 1. Friction head loss relationships

Name	Relationship	Constants
Darcy-Weisbach	$j = \frac{f}{12.1\, D^5} Q^2$	$\frac{1}{\sqrt{f}} = -2\log\Bigg\{\frac{\varepsilon}{3.7D} - \frac{5.02}{R_e}\log\Bigg[\frac{\varepsilon}{3.7D} - \frac{5.02}{R_e}\log\left(\frac{\varepsilon}{3.7D} + \frac{13}{R_e}\right)\Bigg]\Bigg]\Bigg\}$
Manning	$j = \frac{h_f}{L} = \frac{10.29\, N^2}{D^{\frac{16}{3}}} Q^2$	For PVC: N=0.0095
Hazen & Williams	$j = \frac{h_f}{L} = \frac{10.68}{C_{HW}^{1,852}\ D^{4,87}} Q^{1.852}$	For PVC: D=14mm ; C_{HW}=145 - D=25mm ; C_{HW}=146 D=13.3mm ; C_{HW}=148 - D=23.5mm ; C_{HW}=150
Strickler	$j = \frac{10.29}{K^2\ D^{16/3}} Q^2$	K=0.95 (PVC)
Scobey	$j = \frac{h_f}{L} = \frac{1.58}{C_S^{1,886}\ D^{4,87}} Q^{1,887}$	C_{S} = 37 (PVC pipes)
Calmon-Lechapt	$j = \frac{h_f}{L} = a\frac{Q^n}{D^m}$	Smooth pipes: a=0.916.10^{-3} , n=1.78 , m=4.78 Rough pipes: a=1.01.10^{-3} , n=1.84 , m=4.88

Numerous relationships approaching the solution have been developed, and can be integrated into computer software. The most common is known as the Darcy-Weisbach equation (Weisbach, 1845 and Darcy, 1857). It expresses the head loss in terms of the friction coefficient, the flow velocity and the pipe length and diameter. All the other empirical relationships proposed have the merit of expressing the head loss without the complexity introduced by the friction coefficient. They are resumed in Table 1.

A dimensional analysis of the Darcy-Weisbach equation shows that the Darcy friction coefficient (f) is a function of both the relative roughness coefficient (ε/D) and the Reynolds number (Re). Numerous relationships have been derived for the computation of the Darcy friction coefficient, some of them being of implicit type hence requiring a recursive solution. In 1982, a complex relationship expressing the friction coefficient that possesses the advantage of being explicit and highly accurate was derived by (Zigrang and Sylvester, 1982). All the other empirical relationships proposed have the merit of expressing the head loss without the complexity introduced by the friction coefficient.

The pipe roughness coefficients are provided by the manufacturer, and the computation procedure starts by expressing the Reynolds number in terms of the volume flow rate and the pipe dimensions. The Reynolds number is one of the key parameters in the computation of the pressure losses. It allows the determination of the flow regime considered and along with the relative pipe roughness coefficient (ε/D), will influence the approach to determining the coefficient of friction.

Experimental Approach

A hydraulic system apparatus (Boudebza and Bouachari, 1999) essentially constituted of the hydraulic bench illustrated in Figure 1 was used to carrying out the experimentations. It uses diverse pumps and measuring devices. The characteristics of the pipes are represented in Table 1

Table 2. Characteristics of the pipes [14]

Pipe number	Diameter D_i (mm)	Roughness ε (mm)
1	8.5	$8.5\text{x}10^{-6}$
2	13.3	$15.0\text{x}10^{-5}$
3	23.5	$23.5\text{x}10^{-6}$
4	14.0	$2.0\text{x}10^{-2}$
5	25.0	$15.0.10^{-4}$

The hydraulic bench is of volumetric type. It provides a continuous and valve-controlled amount of water supplied through two centrifugal pumps. The pressure loss is determined in terms of head difference using water and mercury manometers, and the volume flow rate is measured by a direct rotameter. The network comprises PVC pipes with different diameters and roughness.

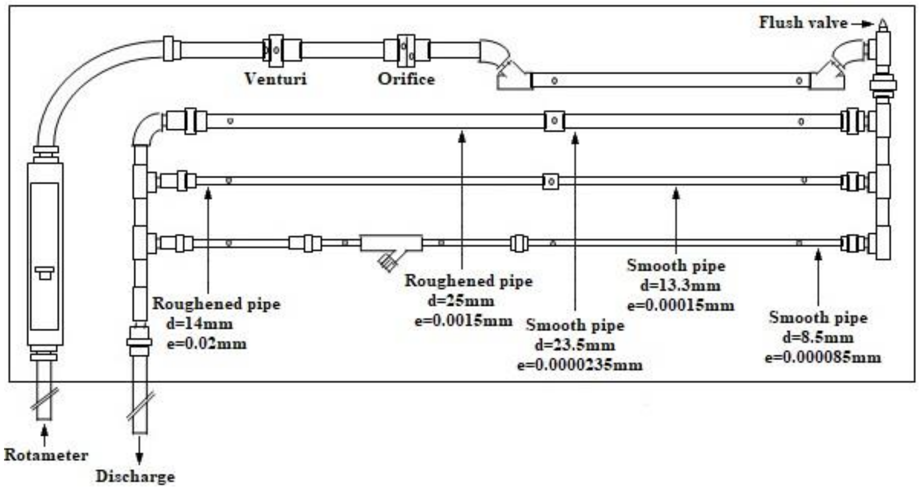

Figure 1. PVC variable diameters and roughness pipes network

Results and Discussion

The friction pressure losses are computed using the six relationships presented in Table 1, and the experimental results are derived from the measurements carried out on the pipe network and hydraulic bench represented in Table 2 and Figure 1.

Figures 2, 3 and 4 present the friction head losses obtained for the three 'smooth' pipes while Figures 5 and 6 show those of the two remaining rough pipes. All the results are expressed in terms of the dimensionless pressure loss (*j*) versus the Reynolds number (*Re*), and all the flow regimes have been found to be turbulent.

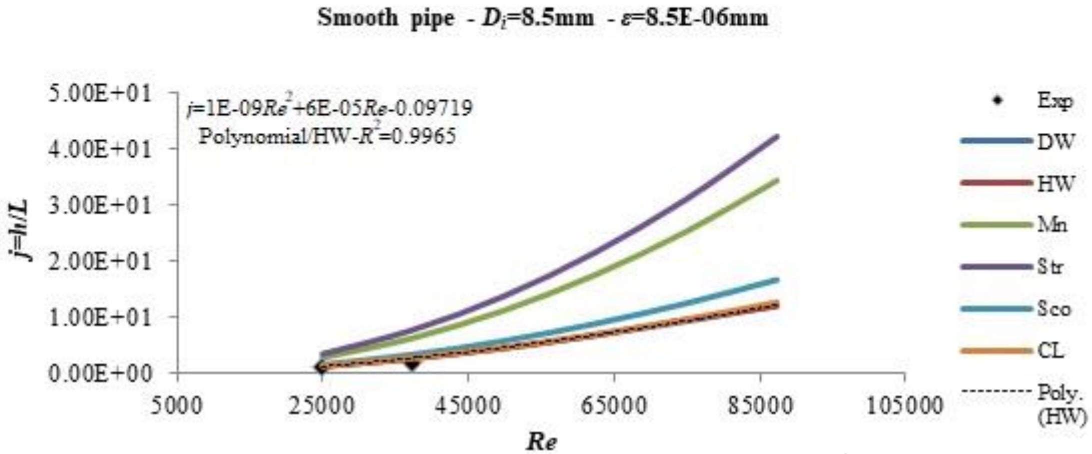

Figure 2. Head loss for a smooth pipe (D_i=8.5mm ; ε=$8.5.10^{-6}$mm)

The Hazen-Williams approach is found to be the most likely to predicting the head loss for the smooth pipes whose results are presented in Figures 2, 3 and 4. This relationship is essentially based on a complex large-spectrum expression for the friction coefficient that leads to satisfactory results. It is widely used in the United States of America since its derivation in 1933.

The increase in the Reynolds number leading to higher errors is noteworthy. This seems to be generated by the displacement of the flow regime from laminar-transitional to turbulent. This difference can be decreased through integrating more relevant coefficients that will take into account the development of the flow regime. It shows the complexity of the problem particularly when faced with distribution networks incorporating numerous pipes of different diameters and roughness.

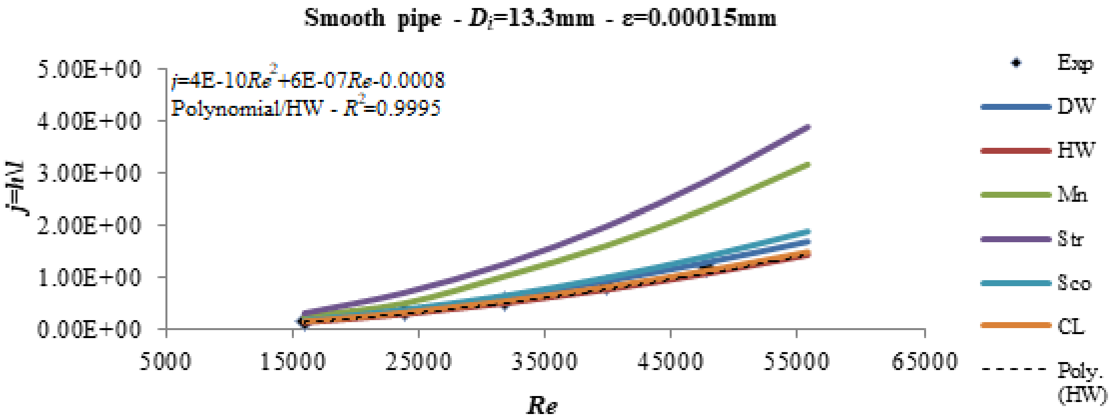

Figure 3. Head loss for a smooth pipe (D_i=13.3mm ; ε=15.0.10^{-5}mm)

An approach consisting of simulating the experimental results by second-order polynomials produced nearly-similar equations that resulted in a residue approaching 0.98 (Maoui, 2016). However, this cannot be ascertained, the approach needing more profound examination.

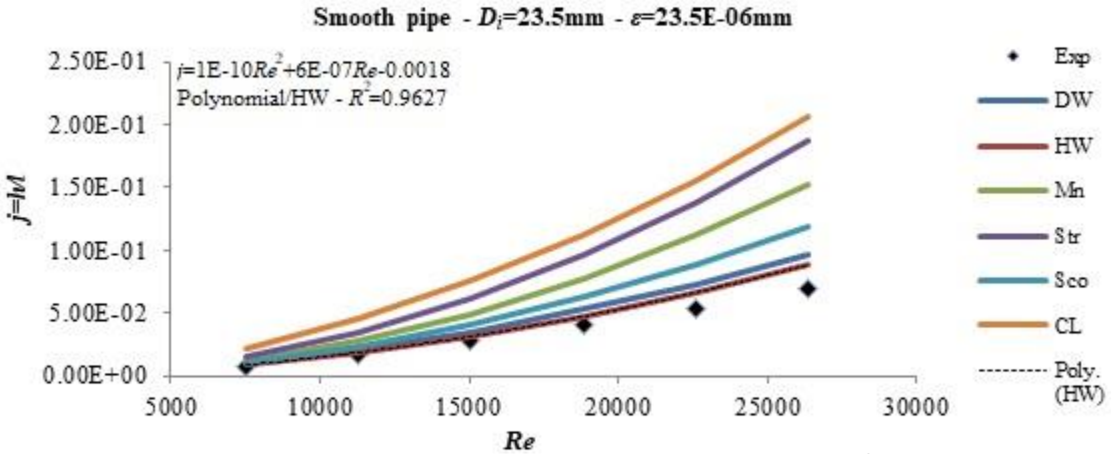

Figure 4. Head loss for a smooth pipe (D_i=23.5mm ; ε=23.5.10^{-6}mm)

The same observations can be made for the case of the two rough pipes whose results are illustrated in Figures 4 and 5. The experimental results show greater head losses than those computed by the different empirical relationships. This difference seems to be essentially generated by the difficulty of correctly predicting the pipe roughness. It is the most important parameter and its value was that proposed by the manufacturer for a new pipe thus omitting the fact that with time, deposits have been accumulating leading to the decrease of the pipe diameter along with the increase of its roughness and consequently boosting the head loss along the pipe.

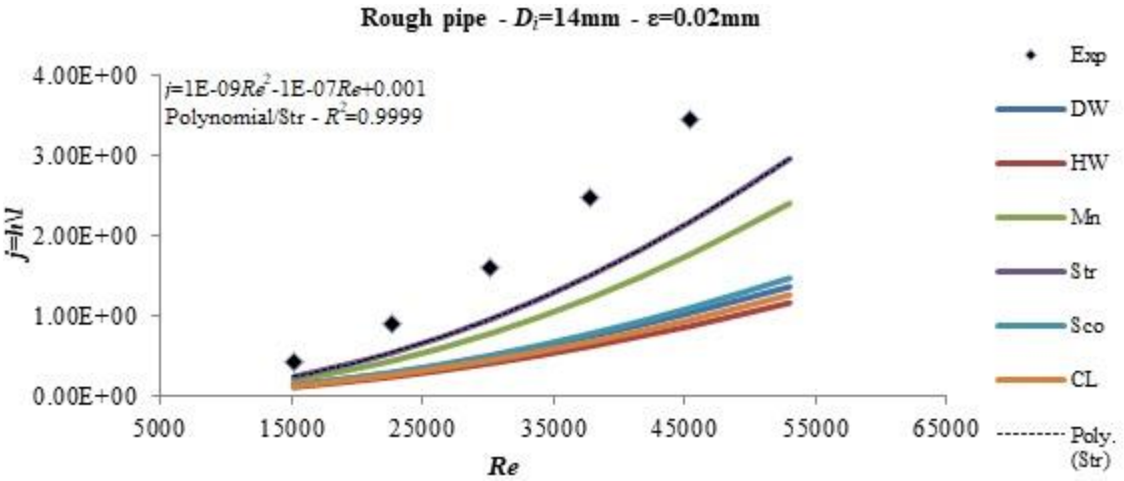

Figure 5. Head loss for a rough pipe (Di=14.0mm ; ε=0.02mm)

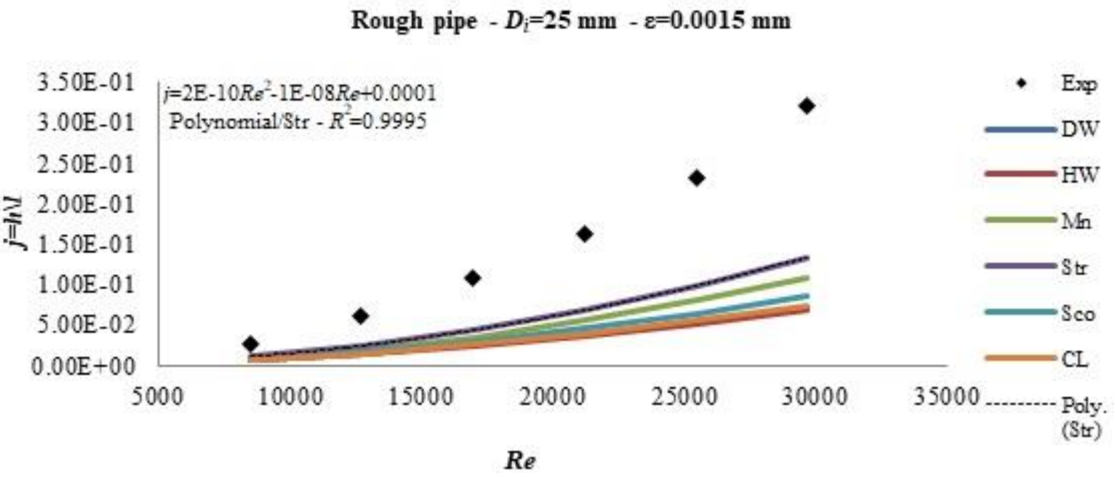

Figure 6. Head loss for a rough pipe (Di=25mm ; ε=0.0015mm)

From what preceded, one can conclude that the transport capacity of the pipes decreases with time (i.e. aging). This reduction is essentially generated either by a decrease in the cross-section due to an accumulation of deposits and an increase in the roughness, or both. The obstruction and the encrustation are the most common forms of such deposits which can vary from 1mm to 10mm in thickness. For the Hazen-Williams formula, the value of 140 is the most commonly used for the coefficient (C_{HW}). It is however understood that for an old pipe in good condition, a value comprised in the interval 100-120 should be acceptable, while for a used pipe 40 to 80 is mostly used. This situation shows the great difficulty faced by the authors in achieving an 'acceptable' value for the coefficients (C_{HW} as well as f and N) used in the developed relationships, and this seem to be the main reason for the relative disparity of the results obtained.

Conclusions

The present study reviewed and applied the different approaches developed over the last decades for the determination of head losses in pipes. These losses are mainly due to friction. The experimental results obtained and their comparison to those computed through applying these relationships show:

1. a preponderance of the Hazen-Williams approach in the case of smooth pipes (i.e. of limited roughness),
2. a better approach by the Strickler relationship in the case of highly rough pipes,
3. the difficulty in determining the friction coefficient particularly when the flows are turbulent,
4. the complexity of evaluation of the roughness coefficient, the value of which is solely provided by the manufacturer in the case of new pipes. Due to erosion and depositing caused by aging, the used pipes are not provided with corresponding roughness coefficients.

An adjustment of the results obtained was attempted through a polynomial approach. This procedure can be interesting and should be further investigated. The present results do however constitute a set of reference data that may be of profit to those interested in the transportation of incompressible fluids inside pipes.

Recommendations

The results and conclusions presented may be subjected to improvements when: (1) considering the determination of the roughness coefficient of aging pipes resulting mainly from erosion-corrosion and deposits etc., (2) determining the pressure losses due to singularities. Indeed, the intermediate region downstream of any accessory is a mixture of both friction and turbulence phenomena, and (3) attempting an adjustment through a polynomial or another function approach.

References

Blasius, H. (1913). Das ahnlichkeitsgesetz in flussigkeiten, Verein Deutscher Ingenieure, Forschungsheft, 131.

Boudebza, C. & Bouachari, A. (1999). Etude des approches de calcul des pertes de charge par frottement et singulières et comparaison avec l'expérimentation, Dipl. Ing., Institut de Génie Mécanique, université 8 Mai 1945, Guelma, Algeria.

CEMAGREF (1983), Calcul des réseaux ramifiés sous pression, 506, Antony, France.

Colebrook, C. F. (1939). Turbulent flow in pipes with articular reference to the transition region between the smooth and rough pipe laws, J. Inst. of Civil Engrs., I1, 133-156.

Darcy H. (1857). Recherches expérimentales relatives au mouvement de l'eau dans les tuyaux, Mallet-Bachelier, atlas, Paris, France.

Ger, A.M. & Holly, E.R. (1976). Comparison of single point injections in Pipe Flow, J. Hydraul. Div., Am. Soc. of Civil Engrs., 102(HY6), 731-746.

Lahiouel, Y. & Haddad, A. (2002). Evaluation of energy losses in pipes, 6th Saudi Engineering Conference, KFUPM, Dhahran, Saudi Arabia, 5, 577-589.

Lamont, P. (1969). The choice of the pipe flow laws for practical use, Water and Water Engineering, 55-63.

Manning R., (1891). On the flow of water in open channels and pipes, Transactions of the Institution of Civil engineers of Ireland.

Maoui, K. (2016). Approche, application et comparaison des pertes de charge dans les conduites de systèmes de distribution d'eau, Master2, Département de Génie Mécanique, Faculté des Sciences et de la Technologie, université 8 Mai 1945, Guelma, Algeria.

Moody, L.F. (1944). Friction factors for pipe flow, Trans. ASME, 66, 671-684.

Powell, R.W. (1968). The origin of Manning formula, J. Hydraul. Div., American Society of Civil Engrs., 1179-1181.

Scobey, F.C. (1966). The flow of water in commercially smooth pipes, Water Resources Center Archives, Series report 17, Univ. of California, Berkeley, USA.

Strickler A., (1923). Beiträge zur Frage der Geschwindigkeitsformel und der Rauhigkeitszahlen fur Ströme, Kanäle und Geschlossene Leitungen, Berna.

Weisbach J. (1845). Lehrbuch der Ingenieur - und Maschinen-Mechanik, vol. 1. Theoretische Mechanik, Vieweg und Sohn, Braunschweig, Germany.

Williams, G.P. (1970). Manning Formula-A Misnomer?, J. Hydraul. Div., American Society of Civil Engrs., 193-200.

Williams, G.S. & Hazen, A. (1933). Hydraulic tables, 3rd Edition, John Wiley & sons inc., USA.

Zigrang, D.J.& Sylvester, N.D. (1982). Explicit Approximations to the Solution of Colebrook's Friction Factor Equation, J. Am. Inst. of Chemical Engrs, 514-515.

Author Information

Abdelkrim Haddad
Laboratoire de Mécanique Appliquée des Nouveaux Matériaux (LMANM),
Université 8 Mai 1945.
PO Box 401, Guelma, Algeria.
Contact E-mail:haddad.abdelkrim@univ-guelma.dz