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An Overview of Colebrook Based Friction Factor Equations for Industrial Pipeline Design: Availability and Applicability

Melvin Ying Fan Kho*[1], Yen Ying Ng[1]

[1] Department of Civil Engineering, Faculty of Engineering, Technology and Built Environment, UCSI University, 56000 Cheras, Kuala Lumpur, Malaysia

Email: melvin.kho2002@gmail.com

Abstract: In the design of industrial pipeline systems, the accurate estimation of the Darcy-Weisbach friction factor is fundamental for determining head loss and ensuring operational efficiency. While the implicit Colebrook-White equation remains the industry standard for turbulent flow, its iterative nature poses computational challenges, leading to the development of numerous explicit approximations. This review paper provides a comprehensive overview of Colebrook-based friction factor equations, examining their availability and applicability across modern engineering practices. Firstly, the study synthesizes findings from recent comparative reviews to identify the most accurate explicit approximations, highlighting equations such as those by Romeo, Royo, and Monzon (2002) and Zigrang and Sylvester (1982) as high-precision alternatives. Secondly, the practical application of these equations is categorized across diverse industries, including hydropower, oil and gas, nuclear engineering, and water distribution, referencing specific industry standards. Finally, the paper critically analyzes the integration of these equations into widely used hydraulic software such as EPANET, OpenFOAM, and WaterGEMS, clarifying the default algorithms and user options available in computational tools. This overview aims to serve as a practical guide for engineers and decision-makers in selecting the most appropriate friction factor correlations for specific industrial scenarios and software environments.

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*Corresponding Author

1. Introduction

Pipelines serve as the arterial network of the modern global economy, providing the most efficient and safe method for transporting fluids across vast distances and supporting a wide range of industries, from municipal water distribution systems to the petrochemical industry. As the liquid flows through the pipeline during transportation, the energy lost occurs due to the friction between the liquid and the lining of the pipe, as well as the interaction between the molecules (Menon, 2015). Hence, friction is often quantified using the Darcy-Weisbach friction factor, f, which is typically expressed in the Colebrook-White equation to determine head loss in the design of water distribution system (Zeghadnia et al., 2019). For example, to estimate the pumping power required, and hence to select the specifications of the pump with adequate capacity and power (Ansu et.al., 2019). Similarly, in the petrochemical industry, determining the Fanning friction factor (f_F) is crucial for the design of pipelines to transport crude oil and other petroleum products under turbulent flow conditions (Kamel et.al., 2018).

The Colebrook-White equation is the classical gold standard implicit function proposed by Colebrook and White (1939) modified from the equations proposed by Von Karman (1930) and Nikuradse (1933) in the early 20th century (Vijayan et al., 2019). While being effective and commonly reffered in the industry, its implicit expression is often considered complex for the user, which requires multiple iterations to ensure accuracy, especially when involving the use of a computer (Jain and Swamee, 1976). Alternatively, while the Moody's diagram is commonly used, the inaccuracy of diagram reading may lead to a larger error in practice, and beside difficult in computer applications (Babajimopoulos and Terzidis, 2013). Hence, multiple explicit expressions such as Swamee-Jain equations, Haaland equations and modifications done by Jain (1976) and so on were introduced to simplify the equation further. This paper aims to review and compare the usage of the standard colebrook based friction factor equations in industry, instead of focusing on the mathematical derivation and expression of the equations.

Generally, the civil and hydraulic engineering sectors predominantly utilize the Darcy-Weisbach friction factor (f), while the chemical and process industries often rely on the Fanning friction factor (f_F). To avoid confusion, this article will focus on equations using the Darcy-Weisbach friction factor, especially on the closed-pipe equations for turbulent flow, as the equation for laminar flow is straightforward. The discussion aims to provide a concise overview for engineers and decision-makers in the industry of the available closed-pipe equations, with their respective applicability and applications. The objective of the review includes:

i. To summarize the commonly used and reviewed Colebrook-based friction factors equations
ii. To summarize the use of equations in industry
iii. To study the integrations of equations in software with examples

2.0 COLEBROOK-BASED FRICTION FACTORS EQUATIONS

Numerous formulas have been proposed to simplify the implicit Colebrook-White equation since 1947, as suggested by Zeghdania et al. (2019), with approximately 33 inventoried in their work. In other words, most of the closed-pipe equations used today are derived from the Colebrook-White equation. On the other hand, Brkić (2011), who reviewed 26 closed-pipe equations, found that most approximations were accurate and usable, with average deviations of less than 3% with some exceptions. For example, Brkić (2011) strongly discouraged the use of 5 approximations due to their high inaccuracy (maximum deviations ranged from 8.2% to 81.24%), including those by Moody (1947), Wood (1966), Eck (1973), Round (1980), as well as Rao and Kumar (2007).

For readers' information, Brkić (2011) also summarised his findings in a table form, ranking the 26 equations in his study by complexity and accuracy, with the equation by Eck (1973) ranked as the least complex equation, and the equation by Serghides (1984) ranked as the most complex equation. In terms of accuracy, the equation proposed by Romeo, Royo, and Monzon (2002) is ranked as the most accurate, with the lowest maximal relative error compared to the implicit Colebrook-White equation, while the equation proposed by Rao and Kumar (2007) is ranked as the least accurate. Table 1 summarizes the top 4 equations with the lowest maximal relative error.

Table 1: Top 4 Equations with the Least Maximal Relative Error (Brkić, 2011)

Equations	Maximal Relative Error (%)
Romeo, Royo, and Monzon (2002)	0.1345
Buzzelli (2008)	0.1385
Serghides (1984)	0.1385
Zigrang and Sylvester (1982)	0.1385

Zeghdania et al. (2019), on the other hand, evaluated and summarised 33 closed-pipe equations, including their respective relative errors, applicable Reynolds number ranges, and relative roughness ranges. Unlike Brkić (2011), who ranked the equations separately based on their individual performance in accuracy and complexity, they ranked the "best equations" based on overall performance, including the accuracy of the formulas, coverage of the entire Moody chart, and the simplicity of the formulas. Overall, they suggested the top 4 equations (see Table 2 below, from best to least), along with their respective maximum deviations from the Colebrook-White equation.

Table 2: Top 4 Equations Suggested by Zeghdania et al. (2019)

Equations	Maximum Deviation (%)
Vatankhah (2014)	0.146
Romeo, Royo, and Monzon (2002)	0.16
Zigrang and Sylvester (1982)	0.17

Alternatively, a recent validation study by Arumugam et al. (2022) included only 11 explicit equations and ranked them based on comparison of the statistical indices and performance error criteria. The 11 explicit equations were selected from 5 different criteria, including 3 equations for simplicity, 2 for accuracy, 3 for mathematical theories and algorithms, 2 equations with no absolute pipe roughness (k_s) parameter, and 1 AI-based explicit equation. They concluded that the Morrison's model demonstrates best performance in terms of accuracy and simplicity, while the widely used Haaland equation and Swamee-Jain equation were also proven to be an effective option with low mean absolute error in terms of frictional loss, as compared to the Colebrook-White equation (measured in metre, m) in their studies. Table 3 shows the ranking of the top 4 best equations, from the best to least, as suggested by Arumugam et al. (2022), along with their

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respective Mean Absolute Error in terms of difference in major friction loss, measured in m.

Table 3: Top 4 Equations with Respective Mean Absolute Error (Arumugam et al. 2022)

Equations	Mean Absolute Error (m)
Morrison (2013)	0.029
Haaland (1983)	0.052
Genić and Jaćimović (2019)	0.063
Swamee and Jain (1976)	0.071

Lastly, López-Silva et al. (2023) reviewed over 30 equations utilizing numerical methods (such as Newton-Raphson), evolutionary algorithms (specifically Gene Expression Programming, GEP), and computational implementations using Python, which not only assess the equations in terms of accuracy, but also on their computational performance. They concluded that the equation proposed by Vatankhah (2018) is the simplest and most accurate for determining the friction factor, with a maximum relative error of less than 0.5%. Overall, López-Silva et al. (2023) recommend 3 equations, as summarised in Table 4. On the other hand, they discouraged the use of 3 equations, including the equations proposed by McKeon et al. (2005), Round (1980), and Referencia (1976) for their inaccuracy and limited application in specific conditions. However, a comparative analysis of the explicit approximations reveals that the equation attributed to "Referencia (1976)" (Eq. 34 in López-Silva et al., 2023) is mathematically identical to the earlier formulation proposed by Wood (1966) in the review by Brkić (2011). This suggests a redundancy in the literature or a potential bibliographic error in the recent review, as the structural form and coefficients are indistinguishable.

Table 4: Top 3 Equations with Respective Maximum Relative Error (López-Silva et al., 2023)

Equations	Maximal Relative Error (%)
Vatankhah (2018)	< 0.5
Chen (1979)	< 1
Offor and Alabi (2016)	< 1

Table 5 attached summarizes the equations recommended and discouraged by Brkić (2011), Zeghdania et al. (2019), Arumugam et al. (2022), and López-Silva et al. (2023), who are referred as "Reviewers" in Table 5. The "Authors" referred to the authors who proposed the equations. A total of 20 equations is included in the list for quick comparison, listed in chronological order, while the number in the box refers to the ranking of equations as suggested by the reviewers, with 1 being the best equations. Nevertheless, only significant equations are included in this study, such as the top equations suggested and the equations discouraged for use according to the reviewers for simplicity and quick reference. The readers are highly recommended to read the papers written by the reviewers for the details on the full list of equations they reviewed. For a better reading experience, the fully expanded equations are attached in the appendix for readers' reference.

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Table 5: Summary of Equations

Authors \ Reviewers	Brkić (2011)	Zeghdania et al. (2019)	Arumugam et al. (2022)	López-Silvaet al. (2023)
Moody (1947)				
Wood (1966)*				
Eck (1973)				
Swamee and Jain (1976)			**4**	
Referencia (1976)*				
Chen (1979)				**2**
Round (1980)				
Zigrang and Sylvester (1982)	**4**	**3**		
Haaland (1983)			**2**	
Serghides (1984)	**3**			
Romeo, Royo, and Monzon (2002)	**1**	**2**		
McKeon et al. (2005)				
Rao and Kumar (2007)				
Buzzelli (2008)	**2**			
Achour (2012)		**4**		
Morrison (2013)			**1**	
Vatankhah (2014)		**1**		
Offor and Alabi (2016)				**2**
Vatankhah (2018)				**1**
Genić and Jaćimović (2019)			**3**	

***Mathematically identical equations**

Legends		
	Suggested	
	Not Suggested	
	Ranking	**(Number)**

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From Table 5, the use of equation proposed by Round (1980) was strongly discouraged by both Brkić (2011) and López-Silva et al. (2023), and hence it should be avoided in industrial pipeline design. On the other hand, beside the commonly used Swamee-Jain equation and Haaland equation in industry, the engineer may opt for another 2 equations with high precision as alternative, which include the equations proposed by Romeo et al. (2002) as well as Zigrang and Sylvester (1982) as suggested by both Brkić (2011) and Zeghdania et al. (2019).

3.0 INDUSTRIAL APPLICATIONS

The equations are widely used across various industries involving pipeline design, including energy industries such as hydropower plant, mining, oil and gas, as well as nuclear engineering beside traditional industries involving water resources management, such as stormwater management, firefighting and agriculture industry. As the closed-pipe equations are primarily used to determine the hydraulic properties of a closed pipe, particularly the friction factor and pipe roughness for further analysis (such as friction loss), any industry involved closed-pipe design or estimation applies the equations.

Table 6 was constructed by synthesizing guidelines from industry-standard manuals and regulatory codes, for example, the Urban Stormwater Management Manual for Malaysia (MSMA 2nd Edition) by Department of Irrigation and Drainage of Malaysia (DID), as well as the Uniform Technical Guideline published by Suruhanjaya Perkhidmatan Air Negara (SPAN) supplemented by recent research articles to verify the practical application of closed-pipe equations across diverse engineering sectors.

Table 6: Examples of Applications of Equations in Different Industries

Industries	Examples of Applications
Hydropower Plant	Design and evaluation on performance of the Penstock of a Hydropower Plant (Çelebioğlu, 2019).
Mining and Slurry Transport	Estimate the pressure losses of slurry with a homogeneous liquid flow pattern in a pipeline (Miedema , 2016).
Oil and Gas	Used in the development of the tubing performance relationship (TPR) model (Hsu & Robinson, 2017).
Nuclear Engineering	Calculating friction factors in pipeline pressure drop computations within 0D/3D CFD coupling framework, which can be used in nuclear safety assessment (Corzo et al., 2023).
Stormwater Management	Estimate the hydraulic capacity of the closed pipe drain and flow velocity of stormwater runoff (DID Malaysia, 2012).
Water Distribution	Determine the suitable size of a pipeline for an external reticulation network and supply mains (SPAN, 2016).
Agriculture	Determine the friction factor of fluid in the irrigation pipe (Samadianfard et al., 2014).
Fire Protection	Estimation of commercial pipe roughness made from different materials for firefighting purposes (Hurley et al., 2016).

Although there are a lot of equations proposed by different researchers as summarized in Table 5, the classical and traditional equations such as the implicit Colebrook-White equation, Moody Chart, Swamee-Jain equation and Haaland equation are more commonly used in industry. For example, the Springer Handbook of Petroleum Technology by Hsu & Robinson (2017) and SFPE Handbook of Fire Engineering by Hurley et al. (2016) only mentioned about Moody Chart, while the MSMA 2nd Edition by DID Malaysia (2012) and Uniform Technical Guideline by SPAN (2016) only mentioned the use of Colebrook-White equation. On the other hand, Haaland equation and Swamee-Jain equation are more commonly used and integrated in software, which we will discuss in the next chapter.

4.0 SOFTWARE INTEGRATION

In industry, hydraulic software plays a pivotal role in the design of industrial pipeline systems, especially when a system in larger scale is involved, for higher efficiency. Hence, it is also crucial for the engineers and decision maker to have a concise overview on the integration and choice of equations for each hydraulic software. The common hydraulic software used in such work incorporating the closed-pipe equations includes OpenFOAM, EPANET, WaterGEMS (or WaterCAD) and Python-based software library as proven by researchers and written in the manual of the software service providers.

OpenFOAM is a free and open source CFD software for problem solving complex fluid flows, especially when it involves chemical reactions, solid mechanics or electromagnetic reactions. (OpenCFD Ltd, 2026). For example, Fahlbeck et al. (2022) incorporated the Haaland equation and Colebrook-White equation in OpenFOAM for turbulent flow, to develop a pressure boundary condition named "headLossPressure" for incompressible flow simulations. In addition, Corzo et al. (2023) also incorporated the Zigrang-Sylverster approach to solve the Colebrook-White equation in the OpenFOAM software, to predict the friction factors in pipeline pressure drop. This serves as a part of the development of Dynamic Boundary Conditions for the modelling of nuclear facilities such as pipelines, tanks and heat exchangers.

According to the user manual of EPANET, a widely used computer program for hydraulic and water behaviour simulation within pressurized pipe network, the program implements the Swamee-Jain equation as the default method for computing the friction factors and pipe modelling in the turbulent flow regime (Rossman et al., 2020). For instance, a case study conducted by Oke et al. (2023) demonstrated the use of EPANET in the design of institutional pipe network in Elizade University, Nigeria to analyse the drawn pipe network, by evaluating the hydraulic parameters such as pipe diameter, flow rate and flow velocity. Alternatively, Fernández-Pato et al. (2025) developed a GPU-accelerated tool named Farming irrigation network Analysis and Simulation (FAST) to accelerate the optimization of pressurized hydraulic networks. They utilized EPANET as a benchmark for validation of their work, which incorporates the Swamee-Jain equation and Colebrook-White equation in their testing.

On the other hand, OpenFlow WaterGEMS (often referred as WaterGEMS) is a product of Bentley, a stronger version or superset of waterCAD for hydraulic modelling of water distribution systems, which support the incorporation with CAD and GIS (Bentley Systems, 2023). An example of work includes the work done by Abdulameer et al. (2022), who utilized waterCAD in their study to compute the relationship between Hazen-Williams and Darcy-Weisbach equations for pipes transporting wastewater in Karbala (Iraq) made of different materials. The Colebrook-White equation was incorporated in the modelling, particularly to determine the friction factor for the use of Darcy-Weisbach equations in their studies.

Lastly, instead of using commercial software, researchers such as Boghetti and Kämpf (2024) incorporated Haaland equation for turbulent flow in the development of PyDHN, an open-source Python library for simulating district heating networks in Verbier, Switzerland. In addition, Kolahi et al. (2025) incorporated the Colebrook-White equation in their Python-based hydraulic model to calculate friction factors for pipe flow in district heating systems. They used this equation alongside the Darcy-Weisbach method to determine head losses in each pipe branch, enabling them to compute pumping power requirements and compare energy consumption between single-pipe and double-pipe configurations in thermal networks.

5.0 CONCLUSIONS

The precise determination of the friction factor is a cornerstone of hydraulic engineering. This review has examined the evolution and applicability of Colebrook-based friction factor equations, ranging from classical implicit forms to modern explicit approximations and their integration into computational tools. The key findings of the review are as follows:

1. The equations proposed by Romeo, Royo, and Monzon (2002) and Zigrang and Sylvester (1982) are highly recommended for their high precision as recommended by 2 groups of reviewers, Brkić (2011) and Zeghdania et al. (2019).

2. Only 2 groups of reviewers out of 4 explicitly discouraged the use of 7 equations, which includes the equations proposed by Moody (1947), Wood (1966), Eck (1973), Rao and Kumar (2007) according to Brkić (2011), and equation by McKeon et al. (2005) according to López-Silva et al. (2023). Both discouraged the use of the equations proposed by Round (1980) and Wood (1966)/Referencia (1976).

3. The Colebrook-based friction factor equations are not only applied in the traditional water-related industry but also implemented in other industries such as nuclear engineering, fire protection as well as oil and gas industry.

4. Although many equations are proposed by researchers, the implicit Colebrook-White equation, Moody Chart, Swamee-Jain and Haaland equations are still widely used across industry and integrated in the hydraulic software.

While this paper provides a comprehensive overview of Colebrook-based friction factor equations and their industrial integration, several limitations should be acknowledged. First, the selection of explicit approximations presented is not exhaustive. Given the vast number of correlations proposed over the last century, this review prioritized equations that have been identified as high-performing benchmarks in recent comparative studies (e.g., Brkić, 2011; Zeghadnia et al., 2019), potentially excluding niche formulations. Second, comparative analysis relies on secondary validation from existing literature rather than primary computational benchmarking by the authors. Consequently, the accuracy rankings discussed depend on the error metrics and datasets used in the cited review papers. Lastly, the industrial applications presented serve as illustrative case studies to demonstrate the practical utility of these equations, rather than a statistical survey of global industry standards. Future research could benefit from a direct computational comparison of these equations within the specific software environments (e.g., comparing OpenFOAM vs. EPANET results) to quantify the impact of solver choice on large-scale network optimization.

This review aims to provide a concise overview for engineers and operators in the choice of Colebrook-based friction factors in their work, by providing them the alternative than the commonly used Swamee-Jain equation and Haaland equation, and also the example of works could be done by the equations.

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Appendix

Formulas proposed by	Expression
Colebrook and White (1939)	$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{k_s}{3.7D} + \frac{2.51}{Re\sqrt{f}}\right)$$
Moody (1947)	$$f = 0.0055\left[1 + \left[\frac{2 \times 10^4 k_s}{D} + \frac{10^6}{Re}\right]^{\frac{1}{3}}\right]$$
Wood (1966)*	$$f = 0.094\left(\frac{k_s}{D}\right)^{0.225} + 0.53\left(\frac{k_s}{D}\right) + 88\left(\frac{k_s}{D}\right)^{0.44} \times Re^{-V}$$ **Where:** $$V = 1.62\left(\frac{k_s}{D}\right)^{0.134}$$
Eck (1973)	$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{k_s}{3.715D} + \frac{15}{Re}\right)$$
Swamee and Jain (1976)	$$f = \frac{0.25}{(\log(\frac{k_s}{3.7D} + \frac{5.74}{Re^{0.9}})^2}$$
Referencia (1976) *	$$f = 0.094\left(\frac{k_s}{D}\right)^{0.225} + 0.53\left(\frac{k_s}{D}\right) + 88\left(\frac{k_s}{D}\right)^{0.44} \times Re^{-1.62\left(\frac{k_s}{D}\right)^{0.134}}$$
Chen (1979)	$$f = \left[-2\log\left(\frac{k_s}{3.7065D} - \frac{5.0452}{Re} log\left[\frac{\left(\frac{k_s}{D}\right)^{1.1098}}{2.8257} + 5.8506Re^{-0.8981}\right]\right)\right]^{-2}$$
Round (1980)	$$\frac{1}{\sqrt{f}} = -1.8\log\left(\frac{Re}{0.135Re\left(\frac{k_s}{D}\right) + 6.5}\right)$$
Zigrang and Sylvester (1982)	$$\frac{1}{\sqrt{f}} = -2\log\left[\frac{k_s}{3.7D} - \frac{5.02}{Re}\log\left[\frac{k_s}{3.7D} - \frac{5.02}{Re}\log(\frac{k_s}{3.7D} + \frac{13}{Re})\right]\right]$$

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Haaland (1983)	$\frac{1}{\sqrt{f}} = -\frac{1.8}{n}\log((\frac{k_s}{3.7D})^{1.11n} + \frac{6.9}{Re})$ n = 1 (liquid) n =3 (gas)
Serghides (1984)	$f = \left(S_1 - \frac{(S_2 - S_1)^2}{S_3 - 2S_2 + S_1}\right)^{-2}$ **Where:** $S_1 = -2log\left(\frac{k_s}{3.7D} + \frac{12}{Re}\right)$ $S_2 = -2log\left(\frac{k_s}{3.7D} + \frac{2.51S_1}{Re}\right)$ $S_3 = -2log\left(\frac{k_s}{3.7D} + \frac{2.51S_2}{Re}\right)$
Romeo, Royo, and Monzon (2002)	$\frac{1}{\sqrt{f}} = -2\log\left[\frac{k_s}{3.7065D} - \frac{5.0272}{Re}\log\left[\frac{k_s}{3.827D} - \frac{4.567}{Re}\log\left[(\frac{k_s}{7.7918D})^{0.9924} + (\frac{5.3326}{208.815 + Re})^{0.9345}\right]\right]\right]$
McKeon et al. (2005)	$f = \left[-1.8\log\left(\frac{6.35 - 1200\left(\frac{k_s}{D}\right)^{1.25}}{Re} + \left(\frac{k_s}{3.15D}\right)^{1.115}\right)\right]^{-2}$
Rao and Kumar (2007)	$\frac{1}{\sqrt{f}} = 2\log\left(\frac{\left(\frac{2k_s}{D}\right)^{-1}}{\left(\frac{0.444 + 0.135Re}{Re}\right) \times \phi(Re)}\right)$ **Where:** $\phi(Re) = 1 - 0.55e^{-0.33\left(ln\left(\frac{Re}{6.5}\right)\right)^2}$
Buzzelli (2008)	$\frac{1}{\sqrt{f}} = B_1 - \left(\frac{B_1 + 2log\left(\frac{B_2}{Re}\right)}{1 + \frac{2.18}{B_2}}\right)$ **Where:** $B_1 = \left(\frac{0.774\ln(Re) - 1.41}{1 + 1.32\sqrt{\frac{k_s}{D}}}\right)$ $B_2 = \frac{k_s}{3.7D}Re + 2.51B_1$

Achour (2012)	$\frac{1}{\sqrt{f}} = -2\log\left[\frac{k_s}{3.7D} + \frac{10.04}{\bar{\mathcal{R}}}\right]$ **Where:** $\bar{\mathcal{R}} = 2Re\left[-\log(\frac{k_s}{3.7D} + \frac{5.5}{Re^{0.9}})\right]$
Morrison (2013)**	$f_F = \left(\frac{0.0076\left(\frac{3170}{Re}\right)^{0.165}}{1 + \left(\frac{3170}{Re}\right)^{7}}\right) + \frac{16}{Re}$
Vatankhah (2014)	$\frac{1}{\sqrt{f}} = -1.997\log\left[0.3523T\left\lvert\log\left(0.3055T^{1.007} + \frac{2.803}{Re^{0.995}}\right)\right\rvert^{0.4} + \frac{2.688}{Re}\left\lvert\log(0.3055T^{1.007} + \frac{2.803}{Re^{0.995}}\right\rvert^{0.6}\right]$ **Where:** $\delta = \frac{6.0173}{Re\,(\frac{0.07k_s}{D} + Re^{-0.885})^{0.109}} + \frac{k_s}{3.71D}$
Offor and Alabi (2016)	$f = \left[-2\log\left[\frac{k_s}{3.71D} - \frac{1.975}{Re}ln\left(\left(\frac{k_s}{3.93D}\right)^{1.092} + \left(\frac{7.627}{395.9 + Re}\right)\right)\right]\right]^{-2}$
Vatankhah (2018)	$f = 0.8686ln\left[\frac{0.3984Re}{(0.8686S)\frac{S - 0.645}{S + 0.39}}\right]^{-2}$ **Where:** $S = 0.12363Re\left(\frac{k_s}{D}\right) + \ln(0.3984Re)$
Genić and Jaćimović (2019)	$f = \left[-1.8\log\left[\frac{7.35 - 1200\left(\frac{k_s}{D}\right)^{1.25}}{Re} + \left(\frac{\left(\frac{k_s}{D}\right)}{3.15}\right)^{1.15}\right]\right]^{-2}$

*Mathematically identical equations

** Expressed in Fanning friction factor f_F instead of Darcy-Weisbach friction factor, f

Legends

Symbol	Description
f	Darcy-Weisbach Friction Factor
f_F	Fanning Friction Factor
k_s	Roughness
D	Hydraulics Diameter
Re	Reynolds Number