

**ERROR ANALYSIS OF NON-ITERATIVE  
FRICTION FACTOR FORMULAS RELATIVE  
TO COLEBROOK-WHITE EQUATION  
FOR THE CALCULATION OF PRESSURE  
DROP IN PIPES**

**Assist.Prof. M. Turhan ÇOBAN**

*Ege University, School of Engineering,  
Department of Mechanical Engineering,  
Bornova, Izmir, Turkiye*

*turhan.coban@ege.edu.tr*

**Abstract**

*Pressure drop in pipes can be calculated by using Darcy-Weisbach formula. In order to use this formula, Darcy friction factor should be known. The best approximation to Darcy friction factor for turbulent flow is given by Colebrook-White equation. This equation can only be solved by numerical root finding methods. There are several other approximate equations to Darcy friction factor with some relative error compared to Colebrook-White equation. In some of these equations the percentage error is so small that they can be used directly in place of Colebrook equation. In this study relative error of several equations are re-evaluated.*

**BORULARDAKİ SÜRTÜNME KAYIPLARI  
ANALİZİNDE DARCY-WEISBACH  
SÜRTÜNME KATSAYISI HESAPLARINDA  
COLEBROOK-WHITE DENKLEMİ YERİNE  
GEÇECEK DÖNGÜSEL OLMAYAN  
ÇÖZÜMLÜ DENKLEMLERİN HATA ANALİZİ**

**Özetçe**

*Borulardaki sürtünme basınç kayıpları Darcy-Weisbach formula ile hesaplanır. Bu basınç kaybını hesaplamak için  $f$  Darcy sürtünme*

*katsayısının hesaplanması gereklidir. Türbülanslı akışlarda Darcy sürtünme katsayısının hesaplanmasında en geçerli yöntem Colebrook-White denklemidir, ancak bu denklem sayısal kök bulma yöntemleri kullanılarak çözülebilen bir denklemdir. Colebrook-White denklemine yaklaşım yapan ve direk olarak çözülebilen çeşitli denklemler mevcuttur. Bu denklemlerin bazılarının Colebrook-White denklemiyle kıyaslandığında hata yüzdeleri çok küçük olduğundan, direk olarak bu denklemin yerine kullanılmaları mümkündür. Yazımızda çeşitli Darcy sürtünme faktörü denklemlerinin Colebrook – White denklemine göre göreceli hatası irdelenmiştir.*

**Keywords:** Darcy –Weisbach pressure drop formula, Pressure drop in pipes, Colebrook equation, Friction factors.

**Anahtar Kelimeler:** Darcy-Weisbach basınç düşümü, Boru içi basınç düşümü, Colebrook denklemi.

## 1. INTRODUCTION

The pressure loss in pipe flow is calculated by using Darcy-Weisbach equation. The equation is given as:

$$\Delta P = f \frac{L}{D} \rho \frac{V^2}{2} \quad (1)$$

In equation (1)  $\Delta P$  is the pressure drop,  $f$  is Darcy friction factor,  $D$  is the hydraulic diameter of the pipe and  $V$  is the average velocity. Darcy friction factor  $f$  depends on the flow regime. For fully developed laminar flow (Reynolds number  $Re < 2100$ ) friction factor can be determined from Hagen-Poiseuille equation as

$$f = \frac{64}{Re} \quad (2)$$

Where,  $Re$  Reynolds number. The definition of the  $Re$  number can be given as:

$$Re = \frac{\rho V D}{\mu} \quad (3)$$

*Error Analysis of Non-Iterative Friction Factor Formulas Relative to Colebrook-White Equation for The Calculation of Pressure Drop in Pipes*

Where  $\rho$  is the density and  $\mu$  is the dynamic viscosity of the fluid. In equation (2) the friction factor changes inversely with Reynolds number. For transition region ( $2100 \leq Re \leq 4000$ ) and turbulent region ( $Re \geq 4000$ ) in smooth as well as rough pipe the friction factor can be described by Colebrook-White equation.

## 2. FRICTION FACTOR EQUATIONS AND ERROR ANALYSIS

Colebrook-White equation (1937)[4]  
Colebrook-White equation can be defined as

$$\frac{1}{\sqrt{f}} = -2 \log_{10} \left[ \frac{(\epsilon/D)}{3.7} + \frac{2.51}{Re \sqrt{f}} \right] \quad (4)$$

Where  $\epsilon/D$  is the relative roughness which is the ratio of the mean height of roughness of the pipe to the pipe diameter. As seen from equation (4) the friction factor is function of Reynolds number and pipe roughness ( $\epsilon$ ). Colebrook-White equation cannot be solved directly due to it's an implicit form as the value of  $f$  appears on both side of the equation. In order to solve equation (4) a numerical root finding method, for example Newton-Raphson method can be used.

Assume

$$X = \frac{1}{\sqrt{f}} \quad (5)$$

$$f(X) = X + 2 \log_{10} \left[ \frac{(\epsilon/D)}{3.7} + \frac{2.51}{Re} X \right] \quad (6)$$

$$\frac{df(X)}{dX} = 1 + 2 \frac{\frac{2.51}{Re}}{\left[ \frac{(\epsilon/D)}{3.7} + \frac{2.51}{Re} X \right]} \quad (7)$$

$$X_{k+1} = X_k - \frac{[f(X)]_k}{\left[ \frac{df(X)}{dX} \right]_k} \quad k = 0, \dots, n \quad (8)$$

Equation (8) is required to be solved iteratively. In order to solve the equation, an initial guess is needed. If the value of the first guess is diverge from the true root value too much equation might converge very slowly or might not converge at all. In order to find the first guess value one of the approximate formulas given below can be used. For example Haaland equation can be used to give the first estimation value for the Colebrook-White equation. The result of some of the approximation equations listed is very close to the result obtained from Colebrook-White equation. When the error level of the new equation is relatively small, requirement of using Colebrook-White equation can be eliminated all together. Calculation of pipe pressure drop usually calculated by computers. Replacing an iterative root finding problem with a directly calculatable equation could save computer calculation time. The simpler equation can be easily computed by using simpler computational environment such as programmable calculators or spreadsheet programs such as MS Excel. Some of the Colebrook-White equation approximation formulas are listed below.

Haaland equation (1983) [23]

A good approximate equation shown. Haaland equation valid for turbulent flow ( $Re > 2300$ )

$$\frac{1}{\sqrt{f}} = -1.8 \log_{10} \left[ \left( \frac{\epsilon / D}{3.7} \right)^{1.11} + \frac{6.9}{Re} \right] \quad (9)$$

Moody equation (1944) [9]

Developed a relationship that is valid for all ranges of Reynolds numbers and relative roughness as follows.

*Error Analysis of Non-Iterative Friction Factor Formulas Relative to Colebrook-White Equation for The Calculation of Pressure Drop in Pipes*

$$f = 5.5 \times 10^{-3} \left[ 1 + \left( 2 \times 10^4 (\varepsilon / D) + \frac{10^6}{\text{Re}} \right)^{1/3} \right] \quad (10)$$

Wood equation (1966) [18]

Its validation region for  $\text{Re} > 10000$ , and  $10^{-5} < (\varepsilon / D) < 0.04$

$$f = a + b \text{Re}^{-c} \quad (11)$$

Where

$$a = 0.53(\varepsilon / D) + 0.094(\varepsilon / D)^{0.225} \quad (12)$$

$$b = 88(\varepsilon / D)^{0.44} \quad (13)$$

$$C = 1.62(\varepsilon / D)^{0.134} \quad (14)$$

Churchill equation (1977) [3]

This equation is valid for all ranges of Reynolds numbers.

$$f = 8 \left[ \left( \frac{8}{\text{Re}} \right)^{12} + (A + B)^{-3/2} \right]^{1/12} \quad (15)$$

Where

$$A = \left[ -2 \log_{10} \left( \frac{(\varepsilon / D)}{3.7} + \left( \frac{7}{\text{Re}} \right)^{0.9} \right) \right]^{16} \quad (16)$$

$$B = \left( \frac{37530}{\text{Re}} \right)^{16} \quad (17)$$

Chen equation (1979) [2]

Chen proposed the following equation for friction factor covering all the ranges of Reynolds number and relative roughness.

$$\frac{1}{\sqrt{f}} = -2 \log_{10} \left[ \left( \frac{(\varepsilon/D)}{3.7065} \right) - \frac{5.0452A}{\text{Re}} \right] \quad (18)$$

Where

$$A = \log_{10} \left( \frac{(\varepsilon/D)^{1.1098}}{2.8257} + \frac{5.8506}{\text{Re}^{0.8981}} \right) \quad (19)$$

Swamee-Jain equation (1976) [14]

Its validation region for  $5000 > \text{Re} > 10^7$ ,  $0.00004 < (\varepsilon/D) < 0.05$ . Swamee-Jain have developed the following equation to the Darcy friction factor.

$$f = \frac{0.25}{A^2} \quad (20)$$

Where

$$A = \log_{10} \left( \frac{(\varepsilon/D)}{3.7} + \frac{5.74}{\text{Re}^{0.9}} \right) \quad (21)$$

Zigrang - Sylvester equation (1982) [20]

Developed a relationship that is valid for all ranges of Reynolds numbers and relative roughness as follows

$$\frac{1}{\sqrt{f}} = -2 \log_{10} \left[ \left( \frac{(\varepsilon/D)}{3.7} \right) - \frac{5.02B}{\text{Re}} \right] \quad (22)$$

$$A = \log_{10} \left( \frac{(\varepsilon/D)}{3.7} + \frac{13}{\text{Re}} \right) \quad (23)$$

$$B = \log_{10} \left( \frac{(\varepsilon/D)}{3.7} - \frac{5.02A}{\text{Re}} \right) \quad (24)$$

*Error Analysis of Non-Iterative Friction Factor Formulas Relative to Colebrook-White Equation for The Calculation of Pressure Drop in Pipes*

Serghides equation (1984) [22]

Serghides equation is an approximation of the implicit Colebrook–White equation. It is valid for all ranges of Reynolds numbers and relative roughness as follows.

$$\frac{1}{\sqrt{f}} = A - \frac{(B-A)^2}{C-2B+A} \quad (25)$$

Where

$$A = -2 \log_{10} \left[ \left( \frac{(\varepsilon/D)}{3.7} \right) + \frac{12}{\text{Re}} \right] \quad (26)$$

$$B = -2 \log_{10} \left[ \left( \frac{(\varepsilon/D)}{3.7} \right) + \frac{2.51A}{\text{Re}} \right] \quad (27)$$

$$C = -2 \log_{10} \left[ \left( \frac{(\varepsilon/D)}{3.7} \right) + \frac{2.51B}{\text{Re}} \right] \quad (28)$$

Goudar- Sonnad equation (2008)[21]

Goudar-Sonnad equation is an approximation of the implicit Colebrook–White equation. This equation is valid for all ranges of Reynolds numbers and relative roughness. It has the following form.

$$\frac{1}{\sqrt{f}} = a \left[ \ln \left( \frac{d}{q} \right) + \delta_{CFA} \right] \quad (29)$$

Where

$$a = \frac{2}{\ln(10)} \quad (30)$$

*M. Turhan ÇOBAN*

$$b = \frac{(\varepsilon / D)}{3.7} \quad (31)$$

$$d = \frac{\ln(10)}{5.02} \text{Re} \quad (32)$$

$$s = bd + \ln(d) \quad (33)$$

$$q = s^{(s/(s+1))} \quad (34)$$

$$g = bd + \ln(d/q) \quad (35)$$

$$z = \left( \frac{q}{g} \right) \quad (36)$$

$$\delta_{LA} = \frac{g}{g+1} z \quad (37)$$

$$\delta_{CFA} = \delta_{LA} \left( 1 + \frac{z/2}{(g+1)^2 + (z/3)(2g-1)} \right) \quad (38)$$

Romeo equation (2002) [11]

Developed a relationship that is valid for all ranges of Reynolds numbers and relative roughness as follows.

$$\frac{1}{\sqrt{f}} = -2 \log_{10} \left[ \left( \frac{(\varepsilon / D)}{3.7065} \right) - \frac{5.0272B}{\text{Re}} \right] \quad (39)$$

$$A = \log_{10} \left[ \left( \frac{(\varepsilon / D)}{7.7918} \right)^{0.9924} + \left( \frac{5.3326}{208.815 + \text{Re}} \right)^{0.9345} \right] \quad (40)$$

$$B = \log_{10} \left( \frac{(\varepsilon / D)}{3.827} - \frac{4.567A}{\text{Re}} \right) \quad (41)$$

*Error Analysis of Non-Iterative Friction Factor Formulas Relative to Colebrook-White Equation for The Calculation of Pressure Drop in Pipes*

In order to determine the relative error of all these approximate formulas, relative error of each equation is with respect to Colebrook-White equation is calculated by using the following equation:

$$Relative\ Error = \frac{(f_{Colebrook-White} - f)}{f_{Colebrook-White}} \times 100 \quad (42)$$

### **3. RESULTS**

The results for the relative error are shown graphically. Results obtained from error analysis are briefly explained below.

- In transition region relative error is too high; as the effect of turbulence increased (for high Reynolds number) the relative error will be decreased. If the approximation formulas are scaled in the order of relative error, Best results are obtained from Goudar-Sonnad equation, Serghides equation, Romeo equation; Ziagrang equation and Chen equation are followed up in the given order.

- When a comparison according to degree of the error is made, Goudar-Sonnad equation with small percentage error order exceeds  $10^{-9}$  % is very close to the result obtained from Colebrook-White equation. Then the next best equation is Serghides equation with percentage error order  $10^{-5}$  % which is also can be used practically.

- Because of these equations is precision enough, the need for use Colebrook-White iterative solution seems to be eliminated.

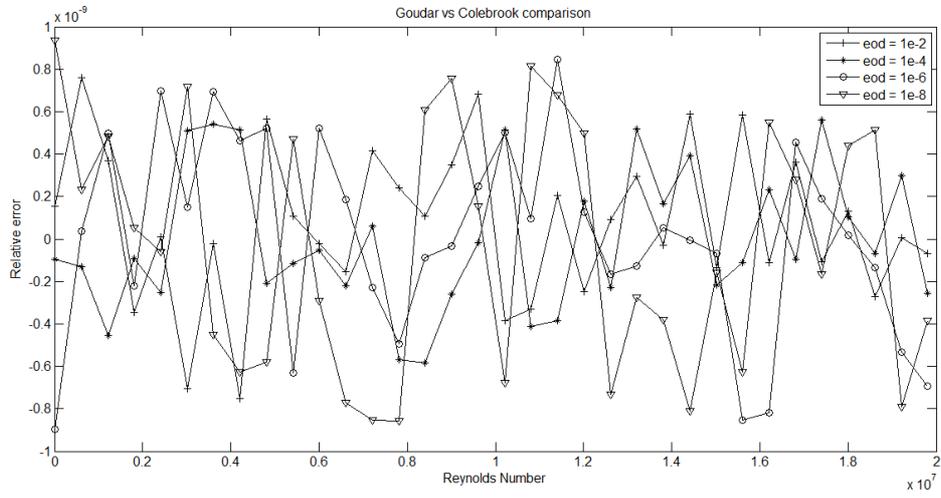


Figure 1. The amount of relative error comparison between Goudar and Colebrook-White equations

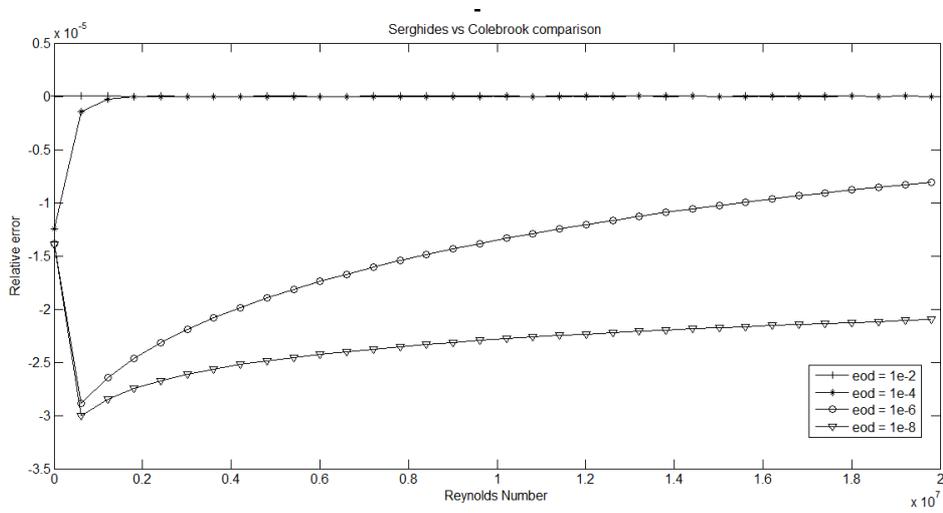
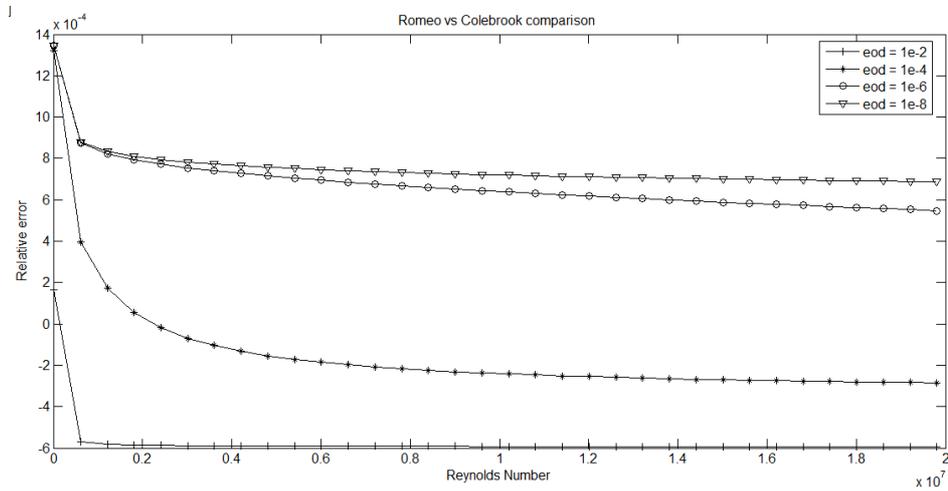
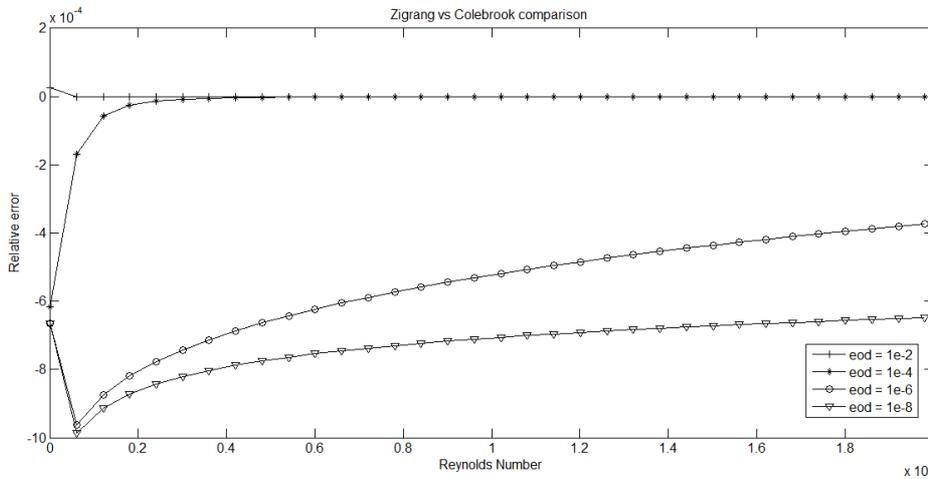


Figure 2. The amount of relative error comparison between Serghides and Colebrook-White equations

*Error Analysis of Non-Iterative Friction Factor Formulas Relative to Colebrook-White Equation for The Calculation of Pressure Drop in Pipes*



*Figure 3. The amount of relative error comparison between Romeo and Colebrook-White equations*



*Figure 4. The amount of relative error comparison between Zigrang and Colebrook-White equations*

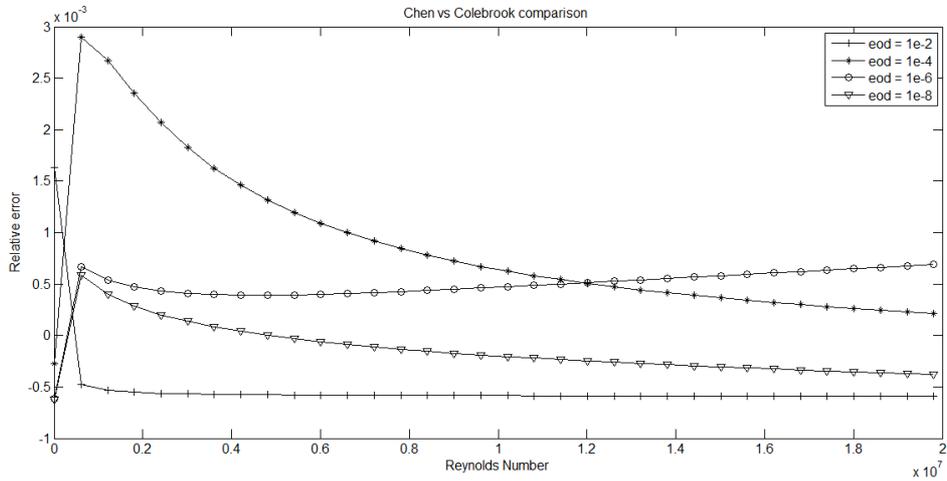


Figure 5. The amount of relative error comparison between Chen and Colebrook-White equations

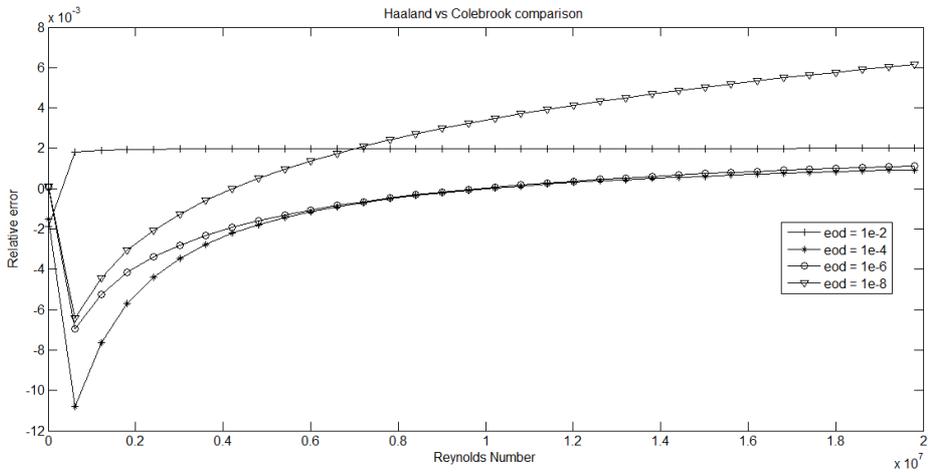


Figure 6. The amount of relative error comparison between Haaland and Colebrook-White equations

*Error Analysis of Non-Iterative Friction Factor Formulas Relative to Colebrook-White Equation for The Calculation of Pressure Drop in Pipes*

**REFERENCES**

- [1]. Barr, D.I.H., "Solutions of the Colebrook-White functions for resistance to uniform turbulent flows.", Proc. Inst. Civil. Engrs. Part 2. 71,1981.
- [2]. Chen, N.H., "An Explicit Equation for Friction factor in Pipe", Ind. Eng. Chem. Fundam., Vol. 18, No. 3, 296-297, 1979.
- [3]. Churchill, S.W., "Friction factor equations spans all fluid-flow ranges.", Chem. Eng., 91,1977.
- [4]. Colebrook, C.F. and White, C.M., "Experiments with Fluid friction roughened pipes.", Proc. R.Soc.(A), 161,1937.
- [5]. Haaland, S.E., "Simple and Explicit formulas for friction factor in turbulent pipe flow.", Trans. ASME, JFE, 105, 1983.
- [6]. Liou, C.P., "Limitations and proper use of the Hazen-Williams equations.", J. Hydr., Eng., 124(9), 951-954, 1998.
- [7]. Manadilli, G., "Replace implicit equations with sigmoidal functions.", Chem.Eng. Journal, 104(8), 1997.
- [8]. McKeon, B.J., Swanson, C.J., Zagarola, M.V., Donnelly, R.J. and Smits, A.J., "Friction factors for smooth pipe flow.", J.Fluid Mechanics, Vol.541, 41-44, 2004.
- [9]. Moody, L.F., "Friction factors for pipe flows.", Trans. ASME, 66,641,1944.
- [10]. Nikuradse, J. "Stromungsgesetze in rauhen Rohren." Ver. Dtsch. Ing. Forsch., 361, 1933.
- [11]. Romeo, E., Royo, C., and Monzon, A., "Improved explicit equations for estimation of the friction factor in rough and smooth pipes." *Chem. Eng. J.*, 86, 369-374, 2002.
- [12]. Round, G.F., "An explicit approximation for the friction factor-Reynolds number relation for rough and smooth pipes.", Can. J. Chem. Eng., 58,122-123,1980.
- [13]. Schlichting, H., "Boundary-Layer Theory" ,McGraw-Hill, New York, 1979.
- [14]. Swamee, P.K. and Jain, A.K., "Explicit equation for pipe flow problems.", J.Hydr. Div., ASCE, 102(5), 657-664, 1976.
- [15]. U.S. Bureau of Reclamation., "Friction factors for large conduit flowing full." Engineering Monograph, No. 7, U.S. Dept. of Interior, Washington, D.C, 1965.
- [16]. Von Bernuth, R. D., and Wilson, T., "Friction factors for small diameter plastic pipes." J. Hydraul. Eng., 115(2), 183-192, 1989.
- [17]. Wesseling, J., and Homma, F., "Hydraulic resistance of drain pipes." Neth. J. Agric. Sci., 15, 183-197, 1967.
- [18]. Wood, D.J., "An Explicit friction factor relationship.", Civil Eng., 60-61,1966.
- [19]. Zagarola, M. V., "Mean-flow Scaling of Turbulent Pipe Flow," Ph.D.thesis, Princeton University, USA, 1996.
- [20]. Zigrang, D.J. and Sylvester, N.D., "Explicit approximations to the Colebrook's friction factor.", AICHE J. 28, 3, 514, 1982.
- [21]. Goudar, C.T. and Sonnad, J.R. , "Comparison of the iterative approximations of the Colebrook-White equation", Hydrocarbon Processing, August 2008, pp 79-83
- [22]. Serghides, T.K., "Estimate friction factor accurately", Chem. Eng. 91, 1984, pp. 63-64
- [23]. White, Frank M., "Fluid Mechanics", Fourth Edition, McGrawHill, 1998, ISBN 0-07-069716-7