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Selami Demir

Yıldız Technical University, Turkey, seldemir@yildiz.edu.tr

Selin Duman

Yıldız Technical University, Istanbul, selinduman4866@gmail.com

Neslihan Manav Demir

Yıldız Technical University, Istanbul, nmanav@yildiz.edu.tr

Aykut Karadeniz

Yıldız Technical University, Istanbul, aykutk@yildiz.edu.tr

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Keywords

MS Excel add-in, Darcy friction factor, Colebrook Equation, Friction factor models

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Selin Duman

*Environmental Engineering Department
Yıldız Technical University
selinduman4866@gmail.com*

Selami Demir

*Environmental Engineering Department
Yıldız Technical University
seldemir@yildiz.edu.tr*

Neslihan Manav Demir

*Environmental Engineering Department
Yıldız Technical University
nmanav@yildiz.edu.tr*

Aykut Karadeniz

*Environmental Engineering Department
Yıldız Technical University
aykutk@yildiz.edu.tr*

Abstract

An MS Excel add-in was prepared for calculating Darcy friction factor. The tool contains a function named “FFACTOR” and it calculates friction factor under laminar, transient, and turbulent conditions. Under turbulent conditions, the function employs a total of 25 friction factor models and the user can select one of these to calculate Darcy friction factor. Tip texts and pop-up help were also prepared and are available if open-source Excel-DNA Intellisense add-in is also added to MS Excel. The students can benefit from the MS Excel add-in. Also, professors can use it for teaching purposes.

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1. Introduction

Darcy-Weisbach equation is a phenomenological model that relates headloss through a pipe or part of it to the mean flow velocity of the fluid. The equation is widely accepted in the form of

$$h_L = \frac{1}{2} \frac{fL}{gD} V^2 \quad (1)$$

where h_L is the headloss over a length of pipe (L), D is internal diameter (or simply diameter) of the pipe, g is gravitational acceleration, and V is the mean flow velocity of fluid. In Eqn. (1), the term f is called the Darcy friction factor or friction factor and most widely calculated using the following formulation by Colebrook [1]:

$$\frac{1}{\sqrt{f}} = -2 \text{Log} \left[\frac{\varepsilon}{3.7D} + \frac{2.51}{Re \sqrt{f}} \right] \quad (2)$$

where ε is the roughness height of the pipe and Re is Reynolds number, which is calculated as follows:

$$Re = \frac{VD}{\nu} \quad (3)$$

In Eqn. (3), ν is kinematic viscosity of the fluid. The Colebrook equation is only valid under turbulent conditions ($Re \geq 4000$). For laminar flow ($Re < 2300$), Darcy friction factor can be calculated by the well-known Hagen-Poiseuille equation:

$$f = \frac{64}{Re} \quad (4)$$

In the transition zone between $2300 < Re \leq 4000$, the value of Darcy friction factor is subject to large uncertainties and this is the main motivation of Cheng's work [2], which provides a detailed discussion of the uncertainty in Darcy friction factor in the transition zone. Although a number of different approaches exist, the general idea is to calculate Darcy friction factor by interpolating from Moody's diagram in the transition zone [3].

Estimation of Darcy friction factor is relatively easy under laminar and transient conditions ($Re < 4000$), however, it becomes difficult to handle under turbulent conditions due to the implicit nature of Colebrook's equation, which requires iterations to calculate the friction factor. For this purpose, spreadsheet programs can be used to calculate Darcy friction factor.

The purpose of the paper is to develop a Visual Basic for Applications (VBA) program in MS Excel for calculating Darcy friction factor. The program consists of a set of user-defined VBA functions. The functions are prepared as an MS Excel add-in so that the students and teachers are free to use the functions in any MS Excel file they wish.

2. Materials and methods

One major drawback of the Colebrook equation is that the model is defined implicitly in friction factor and one needs to make iterations for calculating it. Therefore, a great number of research work have been dedicated to the development of explicit models for calculating Darcy friction factor, by which the students can calculate it easily. Some recent examples include [4- 8].

This paper presents a set of user-defined VBA functions to calculate Darcy friction factor. The functions are prepared as an MS Excel add-in file. This way, the functions will be available in spreadsheet view of MS Excel in any file the user works on. Also, the functions will be available for easy use similar to MS Excel's built-in spreadsheet functions like the functions "SUM", "AVERAGE", "STDEV", etc.

One major drawback related with the use of MS Excel VBA functions is that it is not possible to view functions' tip texts when using them. Fortunately, an open-source MS Excel add-in helps preparing tip texts during the design process and viewing them during the use of user-defined functions. This add-in, Excel-DNA Intellisense, is open-source and is distributed free of charge at <https://github.com/Excel-DNA/IntelliSense>.

The MS Excel add-in for calculating Darcy friction factor was prepared with the help of Intellisense software and tip texts will be available during the use of functions. A number of mathematical models were incorporated into the add-in for calculating Darcy friction factor. Under laminar conditions ($Re < 2300$), Hagen-Poiseuille equation, Eqn. (4), was used while third-order interpolation [3] was used for transient conditions where Reynolds number is between 2300 and 4000. Interpolation formulae are given below.

$$f = X_1 + \frac{Re}{2000} \left[X_2 + \frac{Re}{2000} (X_3 + X_4) \right] \quad (5.a)$$

$$X_1 = 7F_A - F_B \quad (5.b)$$

$$X_2 = 0.128 - 17F_A + 2.5F_B \quad (5.c)$$

$$X_3 = -0.128 + 13F_A - 2F_B \quad (5.d)$$

$$X_4 = \frac{Re}{2000} (0.032 - 3F_A + 0.5F_B) \quad (5.e)$$

$$F_A = Y_3^{-2} \quad (5.f)$$

$$F_B = F_A \left(2 - \frac{0.00514215}{Y_2 Y_3} \right) \quad (5.g)$$

$$Y_2 = \frac{\varepsilon}{3.7D} + \frac{5.74}{Re^{0.9}} \quad (5.h)$$

$$Y_3 = -0.86859 \ln \left(\frac{\varepsilon}{3.7D} + \frac{5.74}{4000^{0.9}} \right) \quad (5.i)$$

A total of 25 formulations were incorporated into the add-in for calculating Darcy friction factor under turbulent conditions ($Re \geq 4000$). A list of these models and related keys for accessing the functions is shown in Table 1. In the table, RR represents relative roughness of the pipe, which is equal to the ratio of roughness height to the internal pipe diameter. Detailed discussions on these formulations are given in [4, 5].

Table 1: Friction factor formulations used

Key	Label	Formulation	Eqn.	Ref.
0	Colebrook	$\frac{1}{\sqrt{f}} = -2 \text{Log} \left[\frac{RR}{3.7} + \frac{2.51}{Re \sqrt{f}} \right]$	(2)	[1]
1	Moody (1947)	$f = 0.0055 \left[1 + \left(2000RR + \frac{10^6}{Re} \right)^{1/3} \right]$	(6)	[6]
2	Altshul (1952)	$f = 0.11 \left(\frac{68}{Re} + RR \right)^{0.25}$	(7)	[7]
3	Wood (1966)	$f = a + \frac{b}{Re^c}$ $a = 0.53RR + 0.094RR^{0.225}$	(8)	[8]

Key	Label	Formulation	Eqn.	Ref.
		$b = 88RR^{0.44}$ $c = 1.62RR^{0.134}$		
4	Churchill (1973)	$\frac{1}{\sqrt{f}} = -2\text{Log} \left[\frac{RR}{3.71} + \left(\frac{7}{Re} \right)^{0.9} \right]$	(9)	[9]
5	Eck (1973)	$\frac{1}{\sqrt{f}} = -2\text{Log} \left[\frac{RR}{3.71} + \frac{15}{Re} \right]$	(10)	[10]
6	Jain (1976)	$\frac{1}{\sqrt{f}} = -2\text{Log} \left[\frac{RR}{3.715} + \frac{5.72}{Re^{0.9}} \right]$	(11)	[11]
7	Swamee-Jain (1976)	$\frac{1}{\sqrt{f}} = -2\text{Log} \left[\frac{RR}{3.7} + \frac{5.74}{Re^{0.9}} \right]$	(12)	[12]
8	Churchill (1977)	$\frac{1}{\sqrt{f}} = -2\text{Log} \left[\left(\frac{64}{Re} \right)^{12} + (A+B)^{-1.5} \right]^{1/12}$ $A = \left[0.8687 \text{Ln} \left(\frac{1}{\frac{0.883(\text{Ln } Re)^{1.282}}{Re^{1.007}} + 0.27RR + \frac{110RR}{Re}} \right) \right]^{16}$ $B = \left(\frac{13269}{Re} \right)^{16}$	(13)	[13]
9	Chen (1979)	$\frac{1}{\sqrt{f}} = -2\text{Log} \left[\frac{RR}{3.7065} + \frac{5.0452A}{Re} \right]$ $A = \text{Log} \left[\frac{RR^{1.1098}}{2.8257} + \frac{5.8506}{Re^{0.8981}} \right]$	(14)	[14]
10	Round (1980)	$\frac{1}{\sqrt{f}} = -1.8\text{Log} \left[0.135RR + \frac{6.5}{Re} \right]$	(15)	[15]
11	Shacham (1980)	$\frac{1}{\sqrt{f}} = -2\text{Log} \left[\frac{RR}{3.7} - \frac{5.02}{Re} \text{Log} \left(\frac{RR}{3.7} + \frac{14.5}{Re} \right) \right]$	(16)	[16]
12	Barr (1981)	$\frac{1}{\sqrt{f}} = -2\text{Log} \left[\frac{RR}{3.7} - \frac{5.158\text{Log} \left(\frac{Re}{7} \right)}{Re \left(1 + \frac{Re^{0.52}}{29} RR^{0.7} \right)} \right]$	(17)	[17]
13	Zigrang-Sylvester (1982)	$\frac{1}{\sqrt{f}} = -2\text{Log} \left[\frac{RR}{3.7} + \frac{5.02B}{Re} \right]$ $A = \text{Log} \left[\frac{RR}{3.7} + \frac{13}{Re} \right]$ $B = \text{Log} \left[\frac{RR}{3.7} + \frac{5.02A}{Re} \right]$	(18)	[18]
14	Haaland (1983)	$\frac{1}{\sqrt{f}} = -1.8\text{Log} \left[\left(\frac{RR}{3.7} \right)^{1.11} + \frac{6.9}{Re} \right]$	(19)	[19]

Key	Label	Formulation	Eqn.	Ref.
15	Serghides (1984)	$\frac{1}{\sqrt{f}} = A - \frac{(B-A)^2}{C-2B+A}$ $A = -2\text{Log}\left[\frac{RR}{3.7} + \frac{12}{Re}\right]$ $B = -2\text{Log}\left[\frac{RR}{3.7} + \frac{2.51A}{Re}\right]$ $C = -2\text{Log}\left[\frac{RR}{3.7} + \frac{2.51B}{Re}\right]$	(20)	[20]
16	Tsal (1989)	$f = \begin{cases} C & \Leftrightarrow C \geq 0.018 \\ 0.0028 + 0.85C & \Leftrightarrow C < 0.018 \end{cases}$ $C = 0.11\left(\frac{68}{Re} + RR\right)^{0.25}$	(21)	[21]
17	Romeo et al (2002)	$\frac{1}{\sqrt{f}} = -2\text{Log}\left[\frac{RR}{3.7065} - \frac{5.0272B}{Re}\right]$ $A = \text{Log}\left[\left(\frac{RR}{3.7}\right)^{0.9924} + \left(\frac{5.3326}{208.815 + Re}\right)^{0.9345}\right]$ $B = \text{Log}\left[\frac{RR}{3.827} - \frac{4.567A}{Re}\right]$	(22)	[22]
18	Goudar-Sonnad (2006)	$\frac{1}{\sqrt{f}} = 0.8686\text{Ln}\left[\frac{0.4587 Re}{(C-0.31)^{C/(C+1)}}\right]$ $C = 0.124 Re RR + \text{Ln}(0.4587 Re)$	(23)	[23]
19	Buzelli (2008)	$\frac{1}{\sqrt{f}} = A - \frac{A + 2\text{Log}\left(\frac{B}{Re}\right)}{1 + \frac{2.18}{B}}$ $A = \frac{0.744\text{Ln} Re - 1.41}{1 + 1.32\sqrt{RR}}$ $B = \frac{RR}{3.7} Re + 2.51A$	(24)	[24]
20	Avcı-Karagöz (2009)	$f = \frac{6.4}{\left[\text{Ln} Re - \text{Ln}\left(1 + 0.01 Re RR\left(1 + 10\sqrt{RR}\right)\right)\right]^{2.4}}$	(25)	[25]
21	Papaevangelou (2010)	$f = \frac{0.2479 - 0.0000947(7 - \text{Log} Re)^4}{\left[\text{Log}\left(\frac{RR}{3.615} + \frac{7.366}{Re^{0.9142}}\right)\right]}$	(26)	[26]
22	Brkic (2011)	$\frac{1}{\sqrt{f}} = -2\text{Log}\left[\frac{RR}{3.71} + \frac{2.18A}{Re}\right]$ $A = \text{Ln}\left[\frac{Re}{1.816\text{Ln}\left(\frac{1.1Re}{\text{Ln}(1 + 1.1Re)}\right)}\right]$	(27)	[27]

Key	Label	Formulation	Eqn.	Ref.
23	Fang et al (2011)	$\frac{1}{\sqrt{f}} = -7874 \text{Ln} \left[0.234RR^{1.1007} - \frac{60.525A}{Re^{1.1105}} + \frac{56.291}{Re^{1.0712}} \right]$	(28)	[28]
24	Ghanbari et al (2011)	$f = \left[-1.52 \text{Log} \left(\left(\frac{RR}{7.21} \right)^{1.042} + \left(\frac{2.731}{Re} \right)^{0.9152} \right) \right]^{-2.169}$	(29)	[29]

3. Application

The MS Excel add-in is meant to be used together with Excel-DNA Intellisense add-in. The Add-ins must be added to MS Excel prior to use. For this purpose, apply the following procedure:

- Start MS Excel.
- Under the “File” ribbon, find “Options” button and click on it.
- Click on the “Add-Ins” tab on the pop-up menu (Fig. 1).
- At the bottom of the window, click “Go...”, browse for the files “Friction_Factor.xlam” and “ExcelDna.Intellisense.xll”. Please note that if 64 bit copy of MS Excel is installed on the computer the 64 bit copy of the add-in, “ExcelDna.Intellisense64.xll”, must be selected (Fig. 2).
- Close all windows by clicking “OK” button.
- Friction_Factor add-in is added to MS Excel and is ready for use.

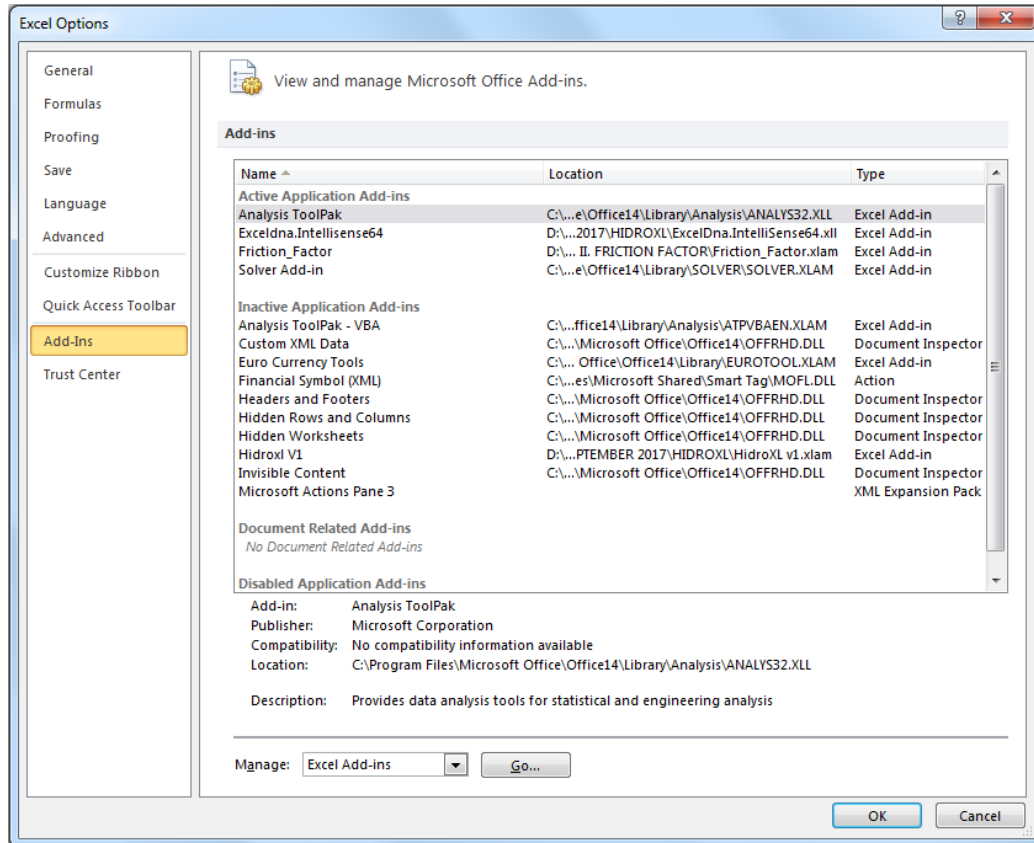


Figure 1: "Add-Ins" tab of "Options" window

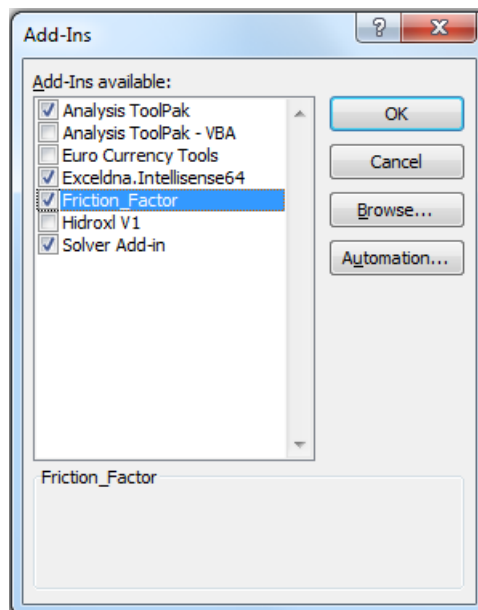


Figure 2: List of available add-ins

The add-in involves a set of functions, although only one function named "FFACTOR" is available on the spreadsheet view. One can use the function by typing

"=FFACTOR(..."

into any cell. Once the function name is typed, the tip text will appear informing the user about the arguments of the function. The function has four arguments. These arguments are shown in Table 2. The function asks these arguments one by one (Fig. 3) and calculates the Darcy friction factor for given conditions. The arguments may be given as numerical values, formulas, other MS Excel built-in functions or user-defined VBA functions, and cell references.

Table 2: Arguments of the function

Argument	Description	Unit
Roughness	Absolute roughness height of the pipe	m
Diameter	Internal diameter of the pipe	m
Velocity	Mean flow velocity in the pipe	m/s
Viscosity	Kinematic viscosity of water	m ² /s
Equation	Optional. User's option on which friction factor equation to be used under turbulent condition.	—

The first four arguments of the function are compulsory and formulas, functions or cell references for these arguments must return numerical values for the function to run properly. The last argument, i.e. "Equation", is optional and may be omitted. If not omitted, this argument must be given with the keys for the equations in Table 1, i.e. 0 for Colebrook equation and 1 for Moody's equation. Please note that this argument will only be used under turbulent conditions ($Re \geq 4000$). The equations in Table 1 will not be used under laminar and transient conditions, thus, the argument will be omitted. If this argument is omitted for $Re \geq 4000$, Colebrook equation will be used to calculate friction factor by default.

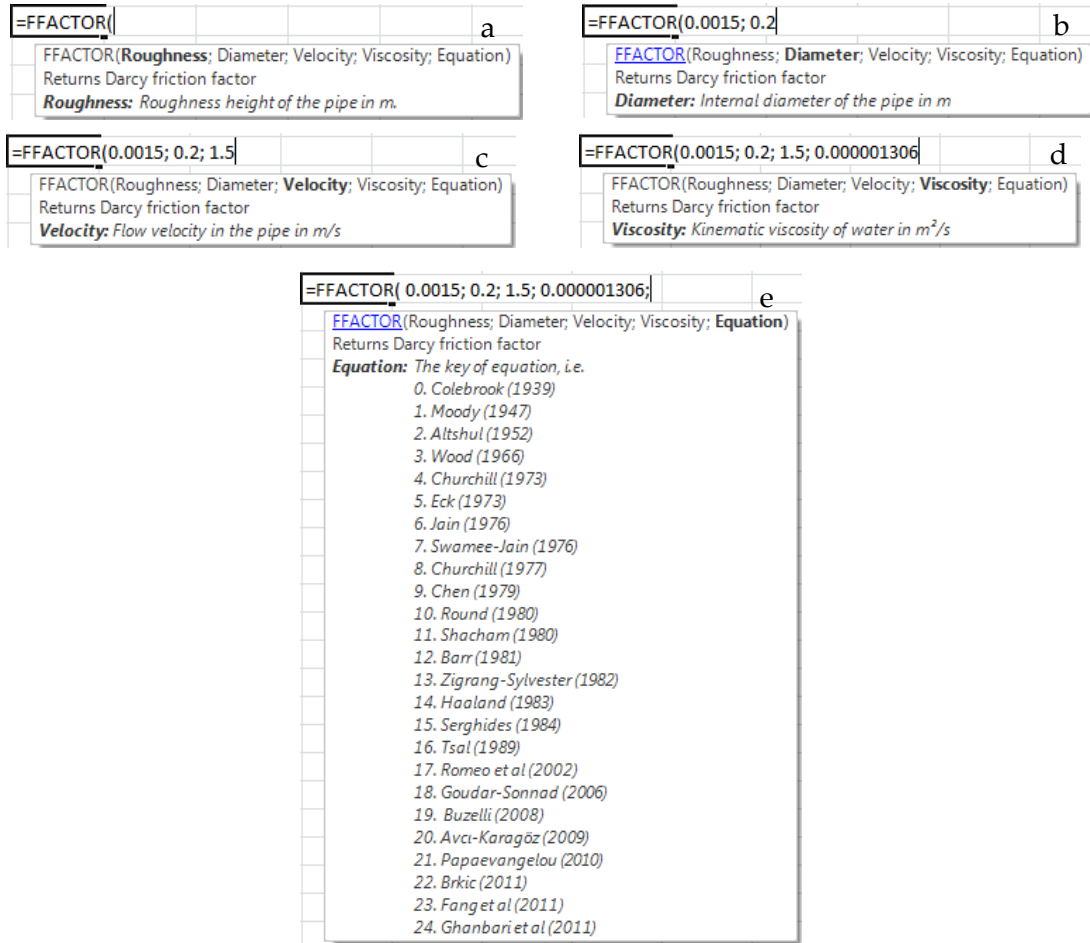


Figure 3: Syntax of the function FFACTOR a. Roughness argument, b. Diameter argument, c. Velocity argument, d. Kinematic viscosity argument, e. Equation key argument

The FFACTOR function was used to calculate Darcy friction factor under turbulent conditions by all equations incorporated. The friction factor was calculated for a relative roughness of 0.0075 and Reynolds numbers between 5266 and $2.63 \cdot 10^7$. Calculated values are shown in Fig. 4. In the figure, the horizontal axis shows the values calculated by Colebrook equation while the vertical axes shows values calculated by respective equations. The red line represents one-to-one values for Colebrook equation. Although the calculated values differ somewhat from those calculated by Colebrook equation, the performances of friction factor formulations are a topic of another paper and detailed discussions are presented in [4, 5].

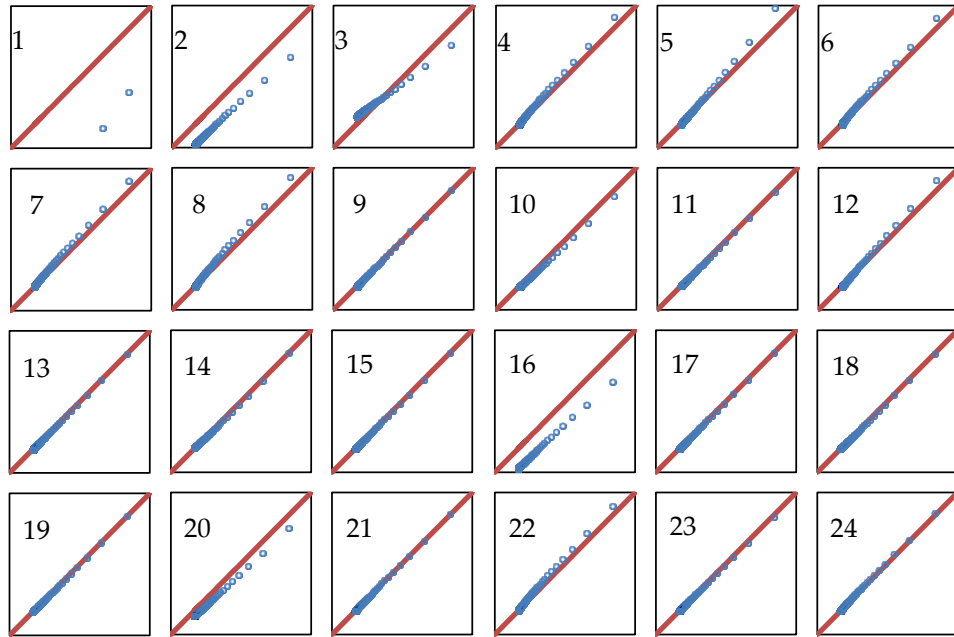


Figure 4: Calculated friction factors by all equations incorporated into the function. The numbers are the keys for equations given in Table 1.

4. Conclusions

An MS Excel add-in was developed and it is available for download together with this paper. The add-in can be used to calculate Darcy friction factor under laminar ($Re < 2300$), transient ($2300 \leq Re < 4000$), and turbulent ($Re \geq 4000$) conditions. Under laminar conditions, the add-in calculates friction factor by well-known Hagen-Poiseuille equation. Third-order interpolation is performed on Moody's diagram under transient conditions. Under turbulent conditions, on the other hand, a total of 25 friction factor models are used for calculating friction factor, depending on the user's choice. The add-in is meant to run together with Excel-DNA Intellisense add-in, which helps creating tip texts for user-defined Visual Basic for Applications (VBA) functions. A tip text was also provided for the add-in on how to use the friction factor function "FFACTOR". The add-in is open-source and is available for both students and teachers.

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