Proceedings of ANES/ASME Solar Joint 2006
XXX Mexican National Solar Energy Week Conference
October 2-6, 2006, Veracruz, Mexico

ANES/ASME2006-0016

DETERMINATION OF THE DARCY PIPE FLOW FRICTION FACTOR AS A ROUTINE IN VISUAL BASIC FOR MS EXCEL

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ABSTRACT

An algorithm for the calculation of the Darcy friction factor, for the estimation of pressure losses in pipe flows, is presented. The algorithm includes the five correlations that generate the Moody chart. The codification of the algorithm in Visual Basic for Applications, for use in the MS Excel spreadsheet, is presented. The Prandtl and Colebrook correlations, which are not explicit in the friction factor, are solved through a Newton numerical method; the derivatives of the functions are obtained through a numerical central perturbation procedure. The algorithm also calculates the values of the friction factor for the critical flow zone, between the zones of laminar and turbulent flow, in order to avoid numeric discontinuities during optimization processes. The results are shown as an Excel-generated Moody chart.

INTRODUCTION

Thermal solar systems always use fluids to transport and/or store energy. In every system, liquids or gases must flow through ducts or pipes, which leads to pressure losses in the flows. It is customary to express this as a “head” loss:

$$h_f = \frac{P_{in} - P_{out}}{\rho g}$$

In order to estimate the magnitude of the flow head losses h_f, the Darcy-Weisbach equation is used:

$$h_f = f \frac{L}{D} \frac{V^2}{2g}$$

This equation is obtained by applying the energy and momentum equations to a straight pipe segment. In it, the factor f is the Darcy Friction Factor, which contains the shear stress between the fluid and the pipe wall. When dealing with laminar flows, an analytical procedure exists to determine the value of the friction factor, which results in the Hagen-Poiseuille equation:

$$f = \frac{64}{\text{Re}}$$

However, if the flow regime is turbulent, no analytical procedure exists to determine the friction factor; thus, it was necessary to turn to dimensional analysis and experimentation in order to establish the functionality between the friction factor and the variables of which it depends. It was found that the friction factor depends on the nature of the fluid, through its density and viscosity. It also depends on the geometry of the duct, through its diameter, roughness and length, and on the flow velocity and flow regime. Dimensional analysis, however, after the grouping of the variables into dimensionless groups, lead to the conclusion that the friction factor is, in general, function of the Reynolds number and the relative roughness. This relationship, obtained through experimentation in commercial pipes, is shown in a graph known as the Moody Chart (1), which is often referred to as the most famous graph of fluid dynamics.

NOMENCLATURE

Symbol	Description	Units
D	Diameter	m
f	Darcy friction factor	-
g	Gravitational acceleration	m / s^2
h_f	Flow head loss	m
L	Pipe length	m
P_{in}	Pressure at pipe inlet	Pa
P_{out}	Pressure at pipe outlet	Pa
Re	Reynolds number	-
V	Velocity	m / s

Greek Symbols

γ	Specific weight	N / m^3
ε	Pipe wall roughness	m
ε / D	Relative roughness	-
ρ	Density	kg / m^3

THE MOODY CHART

For head loss calculations performed “manually”, the determination of the friction factor from the Moody Chart (figure 1) has been used for decades. However, in order to incorporate this calculation into computer programs or electronic spreadsheets, equations are required that describe the functionality of the friction factor with respect to the Reynolds number and the relative roughness, as well as a robust and efficient calculation algorithm.

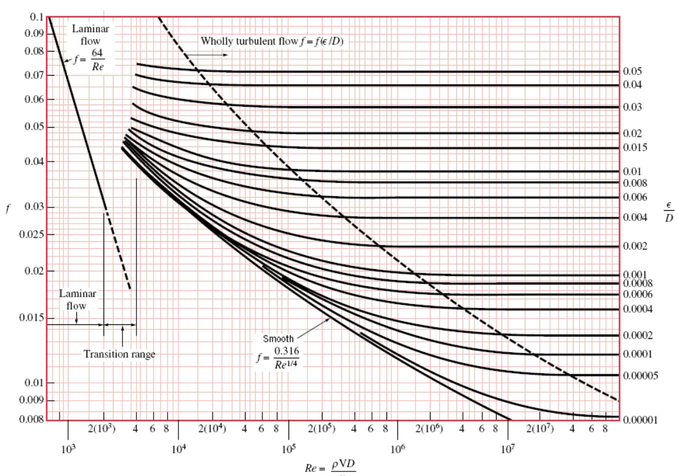

Figure 1. Moody Chart (5)

Correlations for the friction factor calculation

Five correlations exist to numerically determine the friction factor, which completely cover the ranges of Reynolds number and relative roughness that appear in the Moody Chart.

Hagen – Poiseuille equation, for laminar flow in smooth and rough pipes.

$$f = \frac{64}{\text{Re}}$$

Blasius equation, for turbulent flow (4,000 < Re < 10^5) in smooth pipes.

$$f = \frac{0.316}{(\text{Re})^{1/4}}$$

Prandtl equation, for turbulent flow (Re > 10^5) in smooth pipes.

$$\frac{1}{\sqrt{f}} = 2 \log\left(\text{Re}\sqrt{f}\right) - 0.8$$

Colebrook equation, for turbulent flow in the transition zone and rough pipes.

$$\frac{1}{\sqrt{f}} = -2 \log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{\text{Re}\sqrt{f}}\right)$$

Karman equation, for completely developed turbulent flow, rough pipes.

$$\frac{1}{\sqrt{f}} = -2 \log\left(\frac{\varepsilon/D}{3.7}\right)$$

The use of these five equations for the determination of the friction factor guarantees total agreement with the values presented in the Moody Chart. The implementation of this task in a computer program, however, requires an algorithm to select the correct equation for each case and, should it be necessary, to solve it numerically. This algorithm was not found in the available literature, and only alternative procedures were available.

Procedures based on neuronal networks (2) have been published for the calculation of the friction factor. For turbulent flows, the usual is to simplify the calculation process by assuming that the Colebrook equation can be used in all cases, and procedures to implement its solution in electronic spreadsheets have been published (3, 4). They are, however, restricted in range and in the precision reached.

ALGORITHM USED

In this work, an algorithm is presented that uses the five existing equations to precisely reproduce the complete Moody chart. The algorithm has the following functionality:

Knowing the Reynolds number and relative roughness, it selects the correct equation.

In the case of the Prandtl and Colebrook equations, both are solved numerically, since both are non-explicit in the friction factor.

The critical zone, between Reynolds of 2,000 and 4,300, is a zone in which the friction factor is not defined. The Moody chart does not report values for this zone. However, when the numerical simulation of thermal or hydraulic systems is performed, one needs to work with continuous functions, without "holes", in order to ensure that the simulation and/or optimization processes does not abort. Because of this, in the algorithm here presented, the friction factor is calculated continuously, including the critical zone, as shown in Figure 2.

Critical Zone

In the critical zone, the algorithm calculates a friction factor value generated by means of a straight line drawn between the friction factors evaluated as a laminar flow with Reynolds of 2,000, and the value obtained at a Reynolds of 4,300 and the specified relative roughness. The calculated friction factor is located in the straight line, proportional to the provided Reynolds number.

This procedure prevents discontinuities in the calculation of the friction factor, when Reynolds number falls in the critical zone, which can happen both if the conditions of the problem dictate it or during the iterative numerical method used to solve the Prandtl and Colebrook equations. With this, the algorithm acquires robustness and undefined values in the calculation sequences are avoided.

The flow diagram of the algorithm is presented as an annex (figure 3)

NUMERICAL METHOD

The numerical method used for the solution of the two non-explicit equations was a Newton. In it, the first derivative of the function was also numerically determined through a perturbation of 0.01%, forward and backward, of the independent variable.

TRANSITION FLOW OR COMPLETELY DEVELOPED FLOW

In order to determine whether a given combination of Reynolds number and relative roughness corresponded to a flow in the transition zone or to a completely developed flow, a correlation of the dividing line between both zones was obtained, as shown in figures 1 and 2, and used as a discriminator in the selection of the adequate equation. This correlation is coded in the RugRelCritica routine.

IMPLEMETATION IN MS EXCEL

The resulting algorithm was coded in Visual Basic for Applications, for its use in the electronic spreadsheet Microsoft Excel. Its use only requires a call to the subroutine FactorFriccion, providing as arguments the Reynolds number and relative roughness.

RESULTS

In order to ascertain that the algorithm worked, the complete Moody Chart was generated in Excel. A friction factor value matrix was generated, where each cell contained a subroutine call. A range of continuous values of Reynolds number and relative roughness was supplied as arguments for the subroutine calls, and the resulting curves of friction factor at constant relative roughness, as a function of Reynolds number are shown in figure 2.

As can be observed, the obtained results exactly match the Moody Chart shown in Figure 1, which was taken from literature. This demonstrates the ability of the proposed algorithm to accurately calculate the friction factor for any Reynolds number and relative roughness combination. In figure 2, the scale of the axis can not be made to exactly resemble the axis of the Moody Chart taken from the literature, as this is a limitation of the Excel graph.

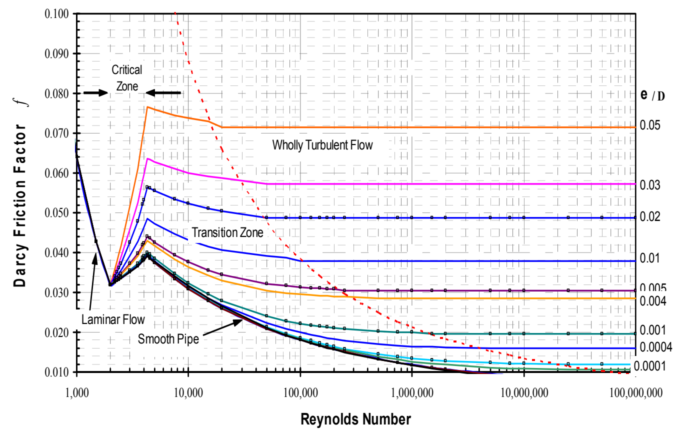

Figure 2. Excel-generated Moody Chart

USE OF THE ALGORITHM

In order to use the algorithm here presented, the Visual Basic editor in MS Excel must be opened, and the routines here presented must be written in a module. From any cell of the spreadsheet, a call is made to the function "=FactorFriccion(Re, RelRough", in which Re and RelRough are the numerical values of the Reynolds number and the relative roughness, for which the friction factor is desired.

The algorithm discriminates any possible case, whether laminar, turbulent in transition, completely developed turbulent, smooth or rough tubing, and returns the value of the correct friction factor.

CODE

The coding of the friction factor calculation algorithm, in Visual Basic for Applications, must be added in Excel, as a module, inside the Visual Basic Editor.

The required functions are:

```
Public Function FactorFriccion(Re, RugRel)
  Select Case Re
    Case Is < 2000#
      FactorFriccion = 64# / Re
      Case 2000# To 4300#
        Fact_1 = 64# / 2000#
        Fact_2 = NewtonUna(4300#, RugRel)
        FactorFriccion = Fact_1 + (Re - 2000) * (Fact_2 - Fact_1) / 2300#
      Case Is > 4300
        If RugRel < 0.000001 And Re < 100000 Then
            FactorFriccion = 0.316 / (Re ^ 0.25)
        ElseIf RugRel > RugRelCritica(Re) Then
            FactorFriccion = (1# / (-2# * Log10(RugRel / 3.7))) ^ 2
        Else
            FactorFriccion = NewtonUna(Re, RugRel)
        End If
    End Select
End Function

Public Function NewtonUna(Re, Rug)
  Xnew = 0.02
  Presicion = 0.00001
  Contador = 0
  Do
    If Xnew < 0# Then Xnew = 0.000001
    Xold = Xnew
    Xnew = Xold - LaFuncion(Xold, Re, Rug) / Derivada(Xold, Re, Rug)
```

```
   If Abs(Xold) > 0.0000001 Then
     ElError = Abs((Xnew - Xold) / Xold)
   Else
     ElError = Xnew
   End If
   Contador = Contador + 1
 Loop Until ((ElError < Presicion) Or (Contador > 100))
 NewtonUna = Xnew
End Function

Public Function LaFuncion(Fact, Re, RugRel)
   If RugRel < 0.000001 Then
      'Prandtl
      LaFuncion = 1# / Sqr(Fact) - 2# * Log10(Re * Sqr(Fact)) + 0.8
   Else
      'Colebrook
      LaFuncion = 1# / Sqr(Fact) + 2# * Log10(RugRel / 3.7 + 2.51 / (Re
* Sqr(Fact)))
   End If
End Function

Public Function Derivada(X, Re, RugRel)
 eps = 0.0001
 Derivada = (LaFuncion(X * (1 + eps), Re, RugRel) - LaFuncion(X * (1 -
eps), Re, RugRel)) / (2 * eps * X)
End Function

Static Function Log10(X)
   Log10 = Log(X) / Log(10#)
End Function

Public Function RugRelCritica(Re)
   RugRelCritica = 232.68 * Re ^ (-0.8755)
End Function
```

REFERENCES

1 Moody, L, Friction Factors for Pipe Flow. ASME Transactions v.66, pp.671. 1944

2 Shayya, W.H.y Sablani, S.S. An artificial neural network for non-iterative calculation of the friction factor in pipeline flow. Computers and Electronics in Agriculture, v.21, n.3, pp. 219-228 December 1998. Elsevier

3 Lester, T. Calculating Pressure Drops in Piping Systems. ASHRAE Journal Sept. 2002

4 Lester, T. Solving for Friction Factor. ASHRAE Journal July, 2003

5 Moran, M.J.; Shapiro, H.N.; Munson, B.R. and DeWitt, D.P. Introduction to thermal systems engineering: Thermodynamics, Fluid Mechanics, and Heat Transfer. John Wiley & Sons. 2003

ANNEX

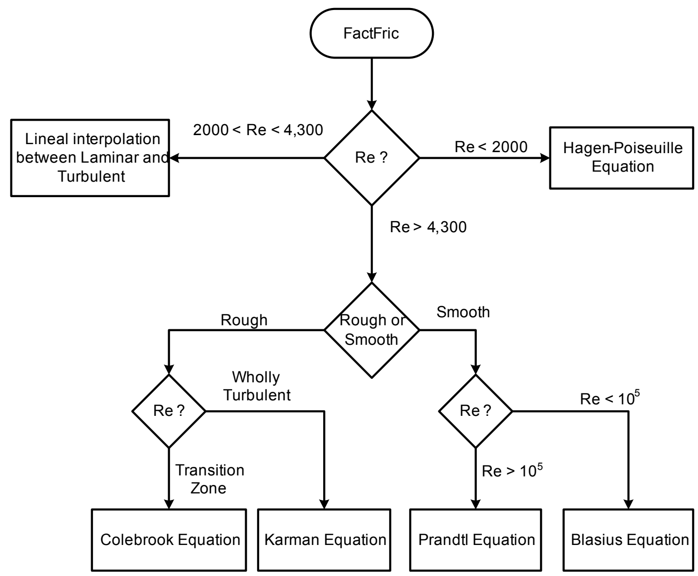

Figure 3. Algorithm flow diagram

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Proceedings of
ANES/ASME XXX National Solar Energy Week
October 2-6, 2006 • Puerto de Veracruz, Veracruz MEXICO

ISBN 0-7918-3791-2
Order No. I758CD

PREFACE

The Solar Joint Meeting between the Asociación Nacional de Energía Solar (ANES) de México and the Solar Energy Division of the American Solar Energy Society (ASME) marks a culminating point in years of planning for stretching collaborative ties between ASME and Solar Energy Organizations across the Americas. In 2004, a joint technical session was held at the International Solar Energy Conference in Portland, Oregon with the Caribbean Solar Energy Society. This year, the ANES extended an invitation to ASME to join their XXX National Meeting in Veracruz, México, October 3-6, 2006. These joint meetings are paving the way to needed collaboration across borders that we hope will accelerate the deployment of renewables across our Hemisphere.

Energy has become a mainstream topic worldwide, and renewables are part of this dialogue. The world has major challenges posted by the rapid changing global and regional climate, due to increases in green house gases and land cover conversion, along with a significant reduction of oil as main conventional energy resource. This is making it obvious that a rapid deployment of renewable energy technologies into the market places is part of the solution. While this situation post challenges to the academic community — by pressing the rapid development of lab based technologies — it represents a unique opportunity for bringing renewables into the market place. Solar, wind, biomass, hydrogen, and energy efficiency technologies and approaches are rapidly becoming part of the solution to the major global problems, probably more than ever before. Hemispherical cooperation is more than essential to take advantage of these new opportunities.

The Solar Energy Division of ASME is extremely pleased with the response of the community to this first joint meeting ANES/ASME. This proceeding contains 20 full peer-reviewed papers in a variety of topics in solar energy and other renewable energy technologies. The topics included are; resource assessment, climate change and renewables, biogas production, solar cooling and refrigeration by absorption and adsorption, energy efficient buildings, solar concentrating power, solar dryer of agricultural products, wind energy, among others. The Proceeding also includes the key-note address by Dr. Frank Kreith, *A Global Perspective of Solar Technologies*. All ASME 20 contributions were organized into four technical sessions within the ANES meeting. The compilation represents an expanded range of applications of solar, wind, and biomass, a reflection of the North/South contributions.

We thank all authors who contributed to this first joint meeting. Our special thanks to the reviewers who anonymously participated in improving the final manuscripts, and to ANES and ASME Solar Energy Division leadership for their support in facilitating this first meeting, which we hope is the first one of many to come.

Sincerely,

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