Virtual Experiment # 1

Skin Friction

Theory

Fluids flowing inside conduits experience resistance to flow not only due to their viscosity but also due to the conduit itself. The contact point between the fluid and the walls of the conduit introduces a type of friction called *skin friction*, while disturbances within the flow such as obstructions, sudden turns, and sudden expansions and contractions in flow area are responsible for *form friction*. The friction in flow generally increases the energy needed to transport a fluid across the length of the pipe.

Skin friction arises from the shearing force exerted by the solid boundary onto the flowing liquid. The larger the surface area of contact, the larger the effect of skin friction would be. The energy needed to overcome the total friction *F* for a fluid flowing inside a conduit is expressed as:

$$F = \frac{u^2}{2g_c}\left(\frac{4fL}{D} + K_f + K_e + K_c\right) \tag{1}$$

where u is the average velocity of the fluid, f is the Fanning friction factor, L is the total straight length of the pipe, D is the internal diameter of the pipe, K_f is the coefficient of form friction, while K_e and K_c are coefficients of friction for sudden expansion and contraction, respectively.

The contribution of skin friction to the total friction is the term $\frac{4fL}{D}$. This is a dimensionless collection of parameters that, when multiplied with $\frac{u^2}{2g_c}$, will give the energy needed to overcome skin friction. The term is dependent on the value of the Fanning friction factor *f*, which can be determined from correlations or graphs. f is a function of Reynolds number and pipe smoothness, but theoretically is defined as:

$$f = \frac{\tau_w}{\frac{1}{2}\rho u^2} \tag{2}$$

where τ_w is the shear stress at the wall of the pipe, ρ is the fluid density and u is the bulk fluid velocity. For laminar flow in smooth tubes, the Fanning friction factor is determined from the Hagen-Poiseuille equation (equation 3):

$$f = \frac{16}{Re} \tag{3}$$

For turbulent flow through smooth pipes, the Blasius equation (equation 4) is used.

$$f = \frac{0.079}{Re^{0.25}} \tag{4}$$

If surface roughness is relevant in calculations, such as for very long pipes, a parameter called relative roughness (ϵ/D) is included. The Churchill equation (equation 5) is used for such purposes (turbulent flow only):

$$\frac{1}{\sqrt{f}} = -4\log\left[0.27\frac{\epsilon}{D} + \left(\frac{7}{Re}\right)^{0.9}\right] \tag{5}$$

An overall equation developed by Churchill is able to represent both the laminar and turbulent region (along with the transition region) in a single equation that also accounts for surface roughness:

$$f = 2\left[\left(\frac{8}{Re}\right)^{12} + \frac{1}{(A+B)^{3/2}}\right]^{1/12} \tag{6}$$

$$A = \left[2.457\ln\frac{1}{\left(\frac{7}{Re}\right)^{0.9} + 0.27\frac{\epsilon}{D}}\right]^{16}$$

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

The energy loss from skin friction can be related to the pressure drop through a length of pipe from the mechanical energy balance for incompressible flow:

$$\frac{-\Delta P}{\rho} = \frac{u^2}{2g_c}\left(\frac{4fL}{D}\right) \tag{6}$$

Objectives

- To compute for the Fanning friction factor for a fluid flowing inside a pipe
- To determine the pressure drop of a fluid flowing inside of a pipe due to skin friction
- To determine the effects to flow parameters to the pressure drop due to skin friction

Precautions

Make sure to take rests in between activities while facing your computer to avoid eye and mind strain. Also, stay hydrated!

Procedure

1. Make sure that you have downloaded the Wolfram Player (https://www.wolfram.com/player/), then download the simulator for the experiment: https://demonstrations.wolfram.com/FrictionalPressureDropInAPipe/
2. In the simulator, you can adjust the following parameters:
    a. Volumetric flow rate
    b. Pipe diameter
    c. Pipe length
    d. Relative roughness
    e. Fluid density
    f. Fluid viscosity
3. Open your FDS document. It contains 2 parts:
    A. Effect of flow rate on friction factor and pressure drop
    B. Effect of pipe length on pressure drop

4. Run the simulator with the given data sets from the FDS. Record your findings and calculate all necessary parameters. Don't forget to attach sample calculations in your FDS.

Guide Questions

Attach your answers to these questions as a group in your FDS.

1. What is the effect of flow rate on the pressure drop?
2. What is the effect of the Reynolds number on the friction factor?
3. Are the friction factors computed from smooth and rough assumptions very different, for all values of Re? Why do you think this is the case?
4. What parameters are affected by pipe length and how does it factor into the determination of pressure drop?
5. Why is there a blip in the friction factor values in the transition region? What is the real trend of the friction factor in the transition region?
6. What combination of parameters minimize the pressure drop due to skin friction?