Cooper Union for the Advancement of Science and Art

Midterm - Design of a Heat Exchanger

ME-407: Computational Fluid Dynamics

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Contents

1 Objective

1.1 Model Assumptions

2 Ballpark Hand Calculations

To verify the CFD results to follow, ballpark hand calculations must be performed.

2.1 Inlet Duct

2.1.1 Velocity Drop Over the Length of the Model

The minimum velocity of 20 mph will be used at the inlet to ensure the worst case scenario is considered.

If we assume the flow is incompressible we can use conservation of mass to calculate the output velocity as shown in Equation 1. Because the inlet area is equal to the outlet area, the average velocity at the outlet is equal to the velocity at the inlet.

$$\begin{aligned} A_1V_1 &= A_2V_2 \\ V_2 &= \frac{A_1V_1}{A_2} \\ &= \frac{A_1V_1}{A_1} \\ &= V_1 \\ \Delta V &= 0 \end{aligned} \tag{1}$$

2.1.2 Pressure Drop Over the Length of the Model

From the Darcy-Weisbach equation[1] the frictional head loss across the duct is given by Equation 2

$$h_f = \frac{fLV^2}{2gD} \tag{2}$$

where

f = the Moody, Darcy, or Stanton friction factor and is a function of Re and $\frac{\epsilon}{D}$
D = hydraulic diameter of the duct
L = length over which the pressure drop occurs
g = acceleration due to gravity
ϵ = roughness factor for the duct

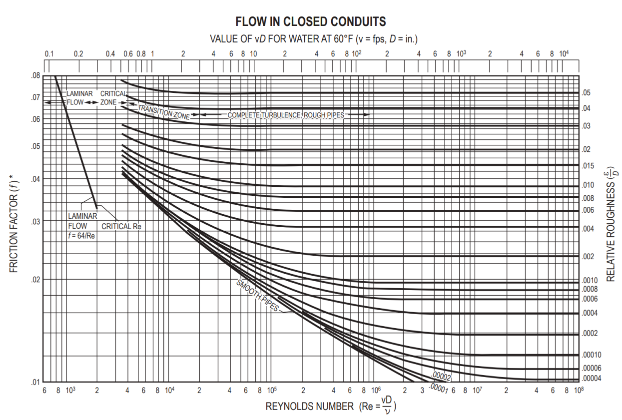

Figure 2.1: Moody Diagram from *Professional Engineer Mechanical Handbook*

To find the friction factor, the Reynolds number must be calculated using Equation 4. However, because the cross-section is not circular the hydraulic diameter must be calculated as shown in Equation 3.

$$\begin{aligned} D_h &= \frac{4A}{P} \\ &= \frac{4*(10in)*(20in)}{2*(10in)+2*(20in)} \\ D_h &= 13.333in \end{aligned} \tag{3}$$

Now the Reynolds number can be calculated using Equation 4. The density and dynamic viscosity of air at the worst case temperature of 108 $^\circ F$ is 0.070 $\mathrm{lb/ft^3}$ and 0.01918 cP respectively according to *Engineering Toolbox*.

$$\begin{aligned} Re &= \frac{\rho VD}{\mu} \\ &= \frac{(0.070lb/ft^3)*(20mph)*(13.333in)}{(0.01918cP)} \\ Re &= 177014.265 \end{aligned} \tag{4}$$

The friction factor can now be found using the Moody chart from the *Professional Engineer Mechanical Handbook* as shown in Figure 2.1. The pipe is assumed to be perfectly smooth, which yields a friction factor of 0.016. The pressure drop can then be calculated using Equation 7. Importantly, the friction factor assumes that the flow is fully developed, which it is not in this case. However, the pressure drop is only being used as a ballpark figure to compare to the CFD results, so this assumption is acceptable.

The head loss due to friction is then calculated using Equation 5 where the length over which the pressure drop occurs is measured from the center path line of the geometry to be 66.648 in.

$$\begin{aligned} h_f &= \frac{fLV^2}{2D} \\ &= \frac{0.016 * (66.648in) * (20mph)^2}{2 * (32.174ft/s^2) * (13.333in)} \\ h_f &= 12.834in \end{aligned} \tag{5}$$

The minor losses from the bend will also be considered. The head loss due to the bend is given by Equation 6. The loss factor K is obtained from *Engineering Toolbox* to be 0.5 for a 45° rounded bend. Although the bend is only 30°, using the loss factor for a 45° bend will give a more conservative estimate.

$$\begin{aligned} h_b &= K\frac{V^2}{2g} \\ &= 0.5\frac{(20mph)^2}{2 * (32.174ft/s^2)} \\ h_b &= 80.23in \end{aligned} \tag{6}$$

The pressure drop is then calculated using Equation 7.

$$\begin{aligned} \Delta P &= \gamma(h_f + h_b) \\ &= (0.070lb/ft^3) * (32.174ft/s^2)(12.834in + 80.23in) \\ \Delta P &= 0.0038psi \end{aligned} \tag{7}$$

2.2 Heat Exchanger

3 Geometry

4 Mesh

4.1 Mesh Quality

5 Model Setup in Fluent

5.1 Boundary Conditions

6 Convergence

7 Results

8 Final Remarks

References

[1] NCEES, *Professional Engineer Mechanical Handbook*, 1.5. NCEES, 2023. [Online]. Available: `https://help.ncees.org/article/87-ncees-exam-reference-handbooks`,
Annotation: Used as a reference for various formulas, best practices, and material properties.

[2] E. Toolbox, *Engineering toolbox*, 2023. [Online]. Available: `https://engineeringtoolbox.com`,
Annotation: Used to find equations for common engineering practice.

[3] T. Baumeister, *Marks' Standard Handbook for Mechanical Engineers*, 12th ed. McGraw-Hill Education, 2017,
Annotation: Used as a reference for various formulas, best practices, and material properties.

[4] T. L. Bergman, *Fundamentals of Heat and Mass Transfer*, Eighth. John Wiley and amp; Sons, Inc, 2017,
Annotation: Used to understand heat transfer principles.

[5] *Matweb material data sheet.* [Online]. Available: `https://www.matweb.com`,
Annotation: Used for material properties.

[6] I. ANSYS, *Ansys fluent user's guide*, Release 2023 R1, Jan. 2023,
Annotation: Used to understand the software and its capabilities.

[7] I. ANSYS, *Ansys fluent theory guide*, Release 2023 R1, Jan. 2023,
Annotation: Used to understand the software and its capabilities.

[8] J. W. Mitchell, *Fox and McDonald's Introduction to Fluid Mechanics*, 10th ed. Hoboken, NJ: John Wiley & Sons, Inc., 2020, ISBN: 978-1-119-61649-8,
Annotation: Used as a reference for fluid mechanics principles.

[9] J. Anderson John D., *Fundamentals of Aerodynamics*, 6th ed. New York, NY: McGraw-Hill Education, 2017, ISBN: 978-1-259-12991-9,
Annotation: Used as a reference for aerodynamics principles.