Homework 12

Ch En 374 – Fluid Mechanics

Due date: 11 Dec. 2019

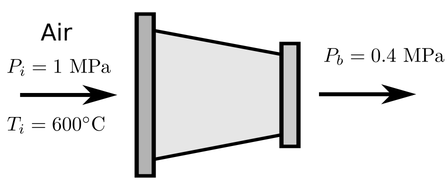
Survey Question

Please report how long it took you to complete this assignment (in hours) in the "Notes" section when you turn your assignment in on Learning Suite.

Practice Problems

1. [Lecture 33 – Pumps and Turbines I]. The performance data of a water pump follow the curve fit $H_{\text{available}} = H_0 - aQ^2$, where the pump's shutoff head is $H_0 = 5.30$ m, the coefficient $a = 0.0453$ m/(Lpm)^2, the units of pump head H are meters, and the units of Q are liters per minutes (Lpm). The pump is used to pump water from one large reservoir to another large reservoir at a higher elevation. The free surfaces of both reservoirs are exposed to atmospheric pressure. The system curve simplifies to $H_{\text{required}} = z_2 - z_1 + bQ^2$, where the elevation difference $z_2 - z_1 = 3.52$ m, and coefficient $b = 0.0261$ m/(Lpm)^2. Calculate the operating point of the pump ($Q_{\text{operating}}$ and $H_{\text{operating}}$) in appropriate units (Lpm and meters, respectively).

2. [Lecture 34 – Pumps and Turbines II]. You are given two pumps with performance curves that fit the equation,
$$H_{\text{available}} = H_0 - aQ^2 \tag{1}$$
with coefficients $H_0 = 2.72$ m and $a = 0.065$ m/(Lpm)^2 for the first pump and $H_0 = 4.78$ m and $a = 0.053$ m/(Lpm)^2 for the second. The units of pump head H are meters, and the units of Q are liters per minutes (Lpm). Use Python to plot the combined performance curve when the pumps are connected (a) in serial for $Q \in [0, 10]$ Lpm and (b) in parallel for $H \in [0, 5]$ m. Which configuration has the potential to give the larger flow rate and which could give the larger head?



3. [Lecture 35 – Compressible Flow]. Hot air from a reactor at 1 MPa and 600°C goes through a converging nozzle into a back-pressure of 0.4 MPa. Determine if the air flow is choked or not. As part of your calculation, determine the critical back-pressure where the flow is no longer choked.

Challenge Problems

4. Answer the following conceptual questions:
   (a) What is the inner diameter of a 1/2-inch, Schedule 40 pipe?
   (b) Which on/off valve is usually cheaper and lighter than a ball valve?
   (c) True or False: A Pitot tube measures a local velocity, which must be accounted for when using it to measure the flow rate in a pipe.
   (d) Give two examples of a positive displacement pump.
   (e) True or False: A centrifugal pump is good when one needs a small pressure increase and a large flow rate.
   (f) Give an example of an impulse turbine.
   (g) True or False: A centrifugal pump provides a larger head at a higher flow rate.
   (h) Explain what NPSH is and how it relates to cavitation.
   (i) True or False: One can place pumps in series to get a larger head than either pump alone.
   (j) True or False: Even when flowing at Ma $\ll 0.3$, one may need to account for the compressibility of natural gas flowing in a long pipeline.

5. The performance data for a centrifugal water pump are shown in the table to the right for water at 77°F (gpm = gallons per minute).

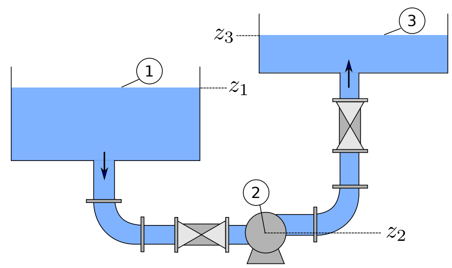
   (a) For each row of data, calculate the pump efficiency. Use these calculations to estimate the volumetric flow rate (gpm) and net head (ft) at the BEP of the pump.

   (b) Plot the pump's performance data H (ft), bhp (hp) and η_{pump} as a function of Q (gpm). Perform a linear least-squares polynomial curve fit to the data for H using a curve that is first order in Q^2. Plot the curve-fit alongside the data.

   (c) Suppose a piping system has a system requirement: $H_{req} = z_2 - z_1 + bQ^2$, where the elevation difference $z_2 - z_1 = 15.5$ ft, and $b = 0.00986$ ft/gpm^2. Estimate the operating point $\{Q_{op}$ (gpm), H_{op} (ft)$\}$ of the system.

Q (gpm)	H (ft)	bhp (hp)
0.0	19.0	0.06
4.0	18.5	0.064
8.0	17.0	0.069
12.0	14.5	0.074
16.0	10.5	0.079
20.0	6.0	0.08
24.0	0.0	0.078

6. A centrifugal pump is used to pump water at 77°F from a reservoir whose surface is 20 ft above the centerline of the pump inlet. The piping system consists of 67.5 ft of PVC pipe with an ID of 1.2 in and negligible average inner roughness. The length of pipe from the bottom of the lower reservoir to the pump inlet is 12.0 ft. There are several minor losses in the piping system: a sharp-edged inlet ($K_L = 0.5$), two flanged smooth 90° regular elbows ($K_L = 0.3$ each), two fully open flanged globe valves ($K_L = 6.0$ each), and an exit loss into the upper reservoir ($K_L = 1.05$). The pump's required net positive suction head is provided by the manufacturer as a curve fit: $\text{NPSH}_{\text{req}} = 1.0\,\text{ft} + (0.0054\,\text{ft/gpm}^2)\,Q^2$, where the volumetric flow rate is in gpm. Estimate the maximum volumetric flow rate (in units of gpm) that can be pumped without cavitation.



Pertinent properties at 77°F:

Property	Value	Units
P_{atm}	14.696	psi
μ	6.002×10^{-4}	lbm/(ft s)
ρ	62.24	lbm/ft^3
P_v	66.19	lbf/ft^2

7. A rigid steel tank of finite volume V is filled with compressed air and at $t = 0$ a valve is to be opened to allow the tank to discharge into the atmosphere. It is desired to predict the resulting tank pressure $P(t)$, if the temperature remains constant at T_0.

   (a) Assuming that $w(t) = \alpha P(t)$, where w is the mass flow rate out of the tank and α is a constant, determine $P(t)$.

   (b) Using what you know about compressible flow, find α. In addition, determine if the form assumed for $w(t)$ in part (a) is valid for choked flow or non-choked flow.