Franklin W. Olin College of Engineering
ENGR 3310: Transport Phenomena

Exam 2

Fall 2004

You have two hours to take this exam. It is a closed-book exam, but you can use two double sided pages of notes (one that you prepared for the first exam, and a second one that you prepare for this exam). You will also need the photocopy of the Moody chart, and the compressible flow tables that I handed out in class.

There are three questions and each question is worth the same amount of points.

The exam is due in my office on Friday, November 19 by 10:00 am. You may turn it in earlier if you wish.

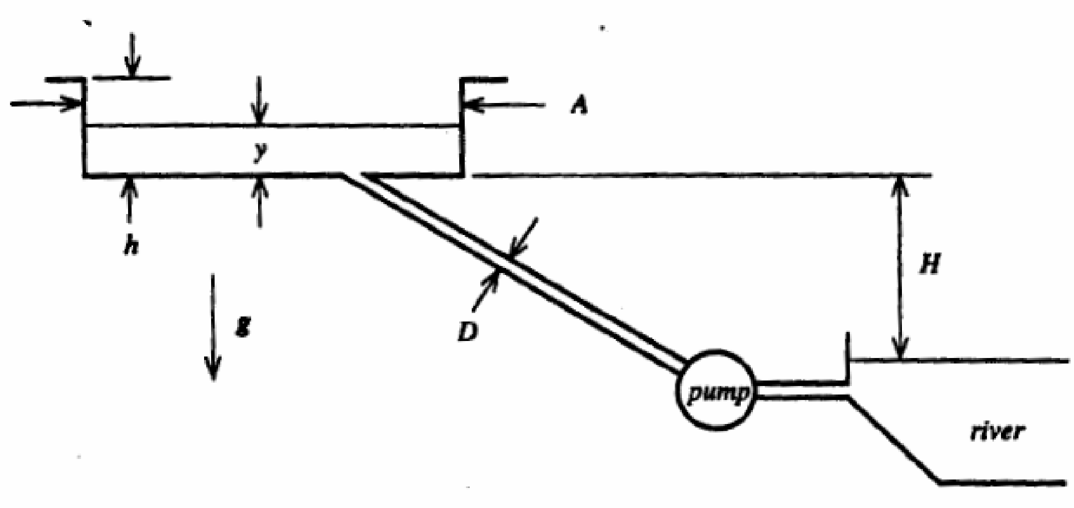
Good luck!

1. Consider a pumped storage hydroelectric plant, such as the Northfield Mountain facility in Western Massachusetts. At times of lower power demand, water from a river is pumped to an upper reservoir. The water is stored in the upper reservoir and then, at times of high electric power demand, is released down the pipe through the pump (which, when run in reverse is used as a turbine generator to generate electricity) and flows back into the river. We will consider only the pumping process in this problem.

The upper reservoir is elevated above the river surface level by a height H = 150 m. The reservoir can be filled to a height h = 10 m by a pump with flow rate Q = 3 m^3/s via a pipe of diameter D = 1 m, roughness height ε = 1 cm and total length L = 1 km. The upper reservoir surface area $A = 1\times10^4$ m^2. The density of water is 1000 kg/m^3 and the viscosity is $\mu = 1\times10^{-3}\,Ns/m^2$.

a) Starting with an empty upper reservoir, how long will it take to fill the reservoir (in hours)?
b) Neglect both major and minor losses. What pump power is required to fill the upper reservoir (in Watts)?
c) Now take into account frictional losses in the pipe. When the upper reservoir is half full (y = 5 m) how much head does the pump need to add to the system (in meters)?

Upper reservoir



More information on the Northfield Mountain facility can be found at
http://www.nu.com/energy/stations/north.asp

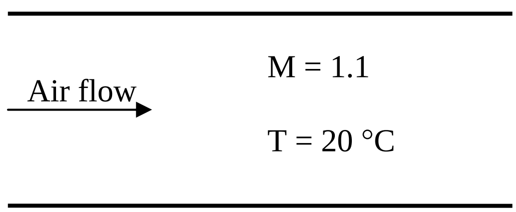
2. A wind tunnel test section with air as the working fluid consists of a long constant area duct with an area of 1 m^2. The Mach number in the test section is set at M = 1.1 and the static temperature is T = 20 °C.

a) What is the velocity of the air in the duct?

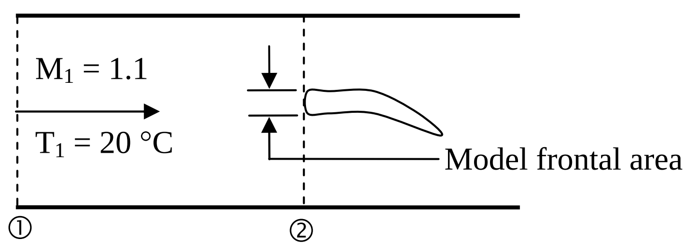
b) A model of an airfoil (wing section) is mounted in the duct. This reduces the effective duct area and the result is a small decrease in duct area. What model frontal area would cause the flow to choke in the duct?

c) If the frontal area of the model is 0.004 m^2, how much does the velocity change between points 1 and 2?

Unblocked Duct



Duct with blockage due to airfoil model



3. A graphite resistor has a diameter of 1 mm and is 20 mm long. The heat generated in the graphite resistor is $\dot{Q}_{gen}$ = 0.5 W. The average heat transfer coefficient is h = 16 W/m^2 K and the surrounding temperature is 300 K. The thermal conductivity of the graphite is 98 W/mK. You can neglect heat conduction out the ends of the resistor.

a) Can the resistor be treated as a lumped system (ie is the lumped thermal capacity model valid)?
b) Write down the differential equation that, when solved, gives you the temperature of the graphite resistor as a function of time. Do not solve this differential equation.
c) What is the steady state temperature of the graphite resistor?
d) To enhance the heat dissipation of the resistor (and also to add electrical insulation) the resistor is sheathed in micanite (crushed mica bonded by a phenolic resin). The average heat transfer coefficient from the micanite is also 16 W/m^2K. The thermal conductivity of micanite is 0.1 W/m K. What thickness of micanite sheath will give the maximum heat dissipation?
e) What is the temperature at the inner wall of the micanite sheath (effectively, the temperature of the graphite resistor)?