ENCH 630: Transport Phenomena

Problem Set 4

Problem 1:

A centrifugal pump has an efficiency of 80% at its optimal design point (where efficiency is maximized) for the case of pumping water at ambient conditions. The impeller diameter is 8 inches. At the optimal design point conditions, the volume flow rate is 800 gallons per minute of water, the stagnation pressure at the pump outlet is 4.5 atm higher than that at the pump inlet, the power input to the pump is 1.66 horsepower, and the impeller rotation rate is 1170 rpm. To obtain a higher flow rate, the pump is to be fitted with a new motor that will operate at 1750 rpm. Use dimensional analysis to find the new flow rate, the new change in stagnation pressure across the pump, and the new power needed for the new pump configuration. You may assume that at the new conditions the pump will operate where its efficiency is maximized.

To begin your analysis, assume that the pump head change (in units of energy per unit mass), the power to the pump (in energy per time), and the pump efficiency (which is dimensionless) are each functions of the volumetric fluid flow rate, the fluid density, the impeller rotation rate (in rpm), the impeller diameter, the fluid viscosity, and the fluid density. Also assume that the difference in height (z) between the pump inlet and outlet is negligibly small. If needed, you may also neglect the difference in fluid velocity between the pump inlet and outlet. You may also make any other reasonable assumptions, but you must fully justify any additional assumptions that you make. Then, using the impeller rotation rate (in rpm), the impeller diameter, and the fluid density as repeating parameters, derive the dimensionless groups that apply. Finally, assume that the effects of viscosity are negligible to arrive at your solution.

Problem 2:

Assume that the shock wave that results from an explosion and that travels through the surrounding fluid medium has spherical geometry (except where it reflects off a solid surface). Also assume that in the <u>*early*</u> stages of an explosion this shock wave has a radius (R) that is a function of time (t), the total amount of energy released in the explosion (E), and the density of the fluid (ρ) that is <u>*in front*</u> of the shock wave (*i.e.,* the density of air before it is disturbed by the explosion).

Use the technique of dimensional analysis and the information given above to find an algebraic relation between R, t, ρ, and E that applies to all explosions in air. If needed, use the concept that if a certain physical phenomenon is described by a single dimensionless number, then that dimensionless number usually has a value approximately of unity.

Use the relation you developed above to estimate the energy released (E) in the atomic bomb test at Alamogordo, New Mexico, in 1945 from the photographs of the shock wave produced during that test shown in Figure 1. Note that a length scale is shown in the photographs in Figure 1, and that the photographs were taken at the times 0.006 s, 0.016 s, 0.053 s, and 0.100 s Determine the value of E for the Alamogordo test both in Joules (J) and in kilotons of TNT (where 1 kiloton of TNT equals 4.2×10^9 J). Also compare your result with the commonly quoted value for *E* of 20 kilotons of TNT for the Alamogordo test.

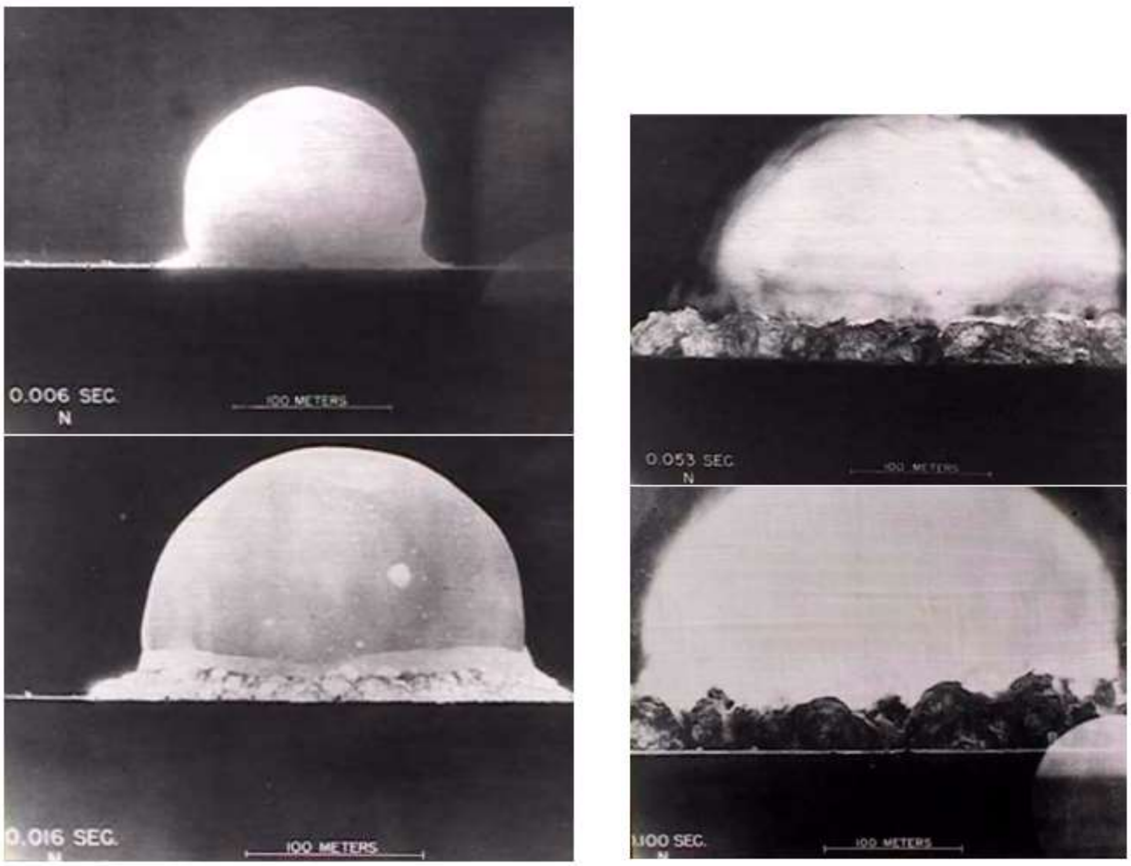

Figure 1. Nuclear explosion data.

Problem 3: Do problem 3A.7 from BSL.

Problem 4: Operation of a pitot tube flow measurement device

As shown Figure 2 below, liquid water at 25°C flows in a horizontal pipe with a diameter of 2.54 cm. A tube connected to the side of the pipe bends into a U shape and returns to the inside of the pipe. The right end of the tube bends with the open end of the tube facing upstream at the center of the pipe. The tube is filled partially with mercury. The part of the tube connected to a hole in the side of the pipe at point B measures the pressure of the liquid at that point. The other end of the tube is located at the center of the pipe at the stagnation point A, and so point A is at the stagnation pressure of the liquid at that point. The tube is filled with liquid water except for the part filled with mercury. The liquid water flowing in the pipe can be considered to be fully developed laminar flow except for the small region where the tube disrupts the flow profile in the pipe. If the difference in the level of liquid mercury between the two sides of the U tube is 0.79 cm, determine the volumetric flow rate in the pipe. **State clearly all assumptions used to arrive at your answer.**

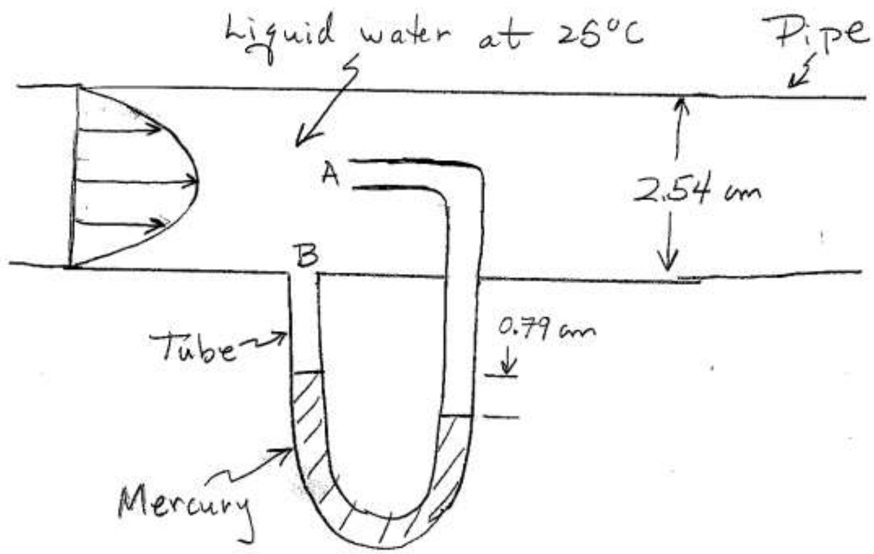

Figure 2. Operation of a pitot tube