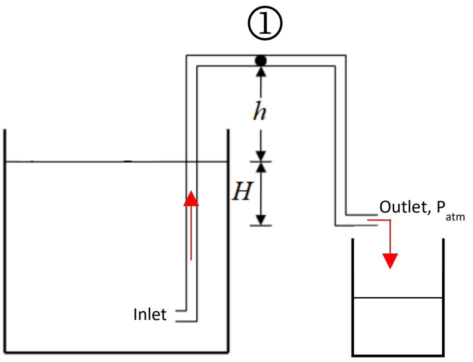

Introduction to Transport Phenomena: Mid-term Exam

<u>Question 1 – Siphon (7 points)</u>

A siphon is a device used for removing liquid from a container using a pipe that rises above the liquid level in the container. A sketch of a typical siphon is shown below.



As you see, no pump or turbine is involved.

The tank contains water, the pipe is 1m above the water level (h) and the siphon outlet is 2m below the level of water in the tank (H). The diameter is constant. Friction losses can be neglected.

a) Calculate the water velocity at the siphon outlet and the pressure at point 1. Be smart and figure out the solution with the given information :)

b) Briefly explain the working principle of a siphon in 1-2 sentences. The result of the pressure at point 1 will help you to provide this explanation.

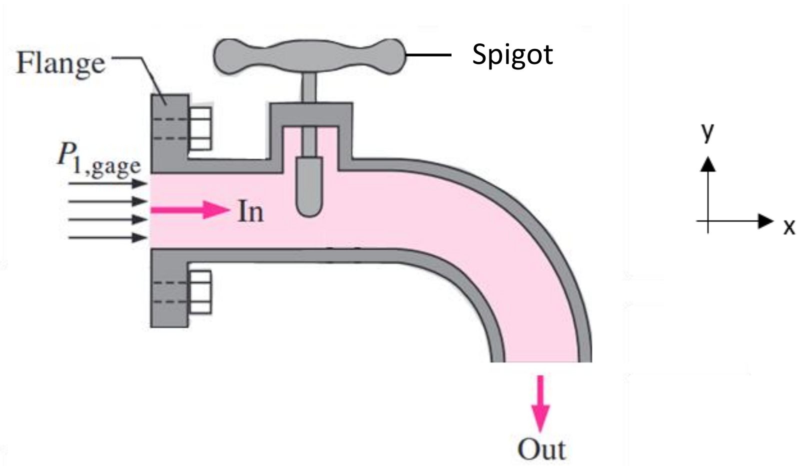
c) Assume that the water velocity in the entire pipe is the same that you calculated at point a). Calculate the theoretical physical limit for the height of the top of the siphon above the water surface (i.e. the maximum h possible).

d) The value you find in c) cannot be reached in reality. At some point, the pressure in the pipe reaches the vapor pressure of the liquid. So, vapor bubbles form and they interfere with the flow. This phenomenon is called “cavitation” and causes problems with operating the siphon.

Knowing that the vapor pressure of water at 25°C is 3.169 kPa, calculate the siphon height that can be reached without cavitation.

Question 2 – Forces Applied on a Faucet (11 points)

Water flows at a rate of 1.17 L/s through a flanged faucet with a partially closed gate valve spigot (K_L = 17). The inner diameter of the pipe at the location of the flange is 2 cm and is constant in the faucet. The pressure at the faucet entry at the location of the flange is measured to be 90 kPa (gauge). The pressure at the outlet is atmospheric pressure. The total mass of the faucet assembly plus the water within it is 5.7 kg. Calculate the reaction force of the flange in the x and y directions.



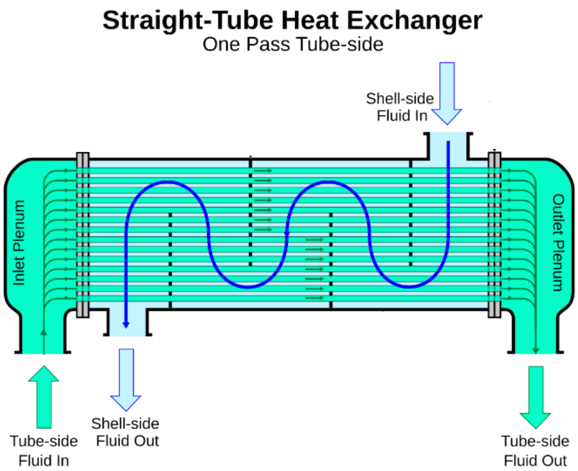
Additional instructions. Take into account frictional forces in the flange faucet, $F_{friction} = \Delta P_f \cdot A$

Consider than 50% of the total friction force modulus is applied horizontally and 50% of the total friction force modulus is applied vertically. K_L for a 90° elbow is 0.2. Consider that water travels a total length of L = 0.5 m before the spigot. The roughness of the faucet material is ε = $2 \cdot 10^{-5}$ m. The dynamic viscosity of water is $9 \cdot 10^{-4} \frac{kg}{m \cdot s}$.

Question 3 – Shell-and-Tube Heat Exchanger (10 points)

A shell-and-tube heat exchanger is designed to heat water having a mass flow rate of 20’000 kg/h from 40°C to 60°C. Pressurized liquid water at 180°C is used as the heat source and flows through tubes with a mass flow rate of 10’000 kg/h. The tubes have an inner diameter of D = 20 mm, the Reynolds number is Re = 10’000. The overall heat transfer coefficient of the heat exchanger is estimated to be U = 450 $W/m^2 \cdot K$.

Throughout the problem, you can assume that the properties of water are constant. The heat capacity of water is 4.181 kJ/kg·K, its density is 908.3 kg/m^3 and its dynamic viscosity is $1.704 \cdot 10^{-4}$ Pa·s.



a) Calculate the heat transfer rate $\dot{Q}$ of the heat exchanger and the exit temperature of the hot fluid.

b) If the heat exchanger is counterflow with one tube and one shell pass as on the schematic image above, first of all draw the temperature profile across the heat exchanger.

Then, determine:

1. The heat transfer area
2. The velocity of the hot fluid through the tubes

If the total cross-sectional area of all the tubes taken together is 0.033 m^2, calculate:

3. The total number of the tubes and the length of the heat exchanger.

Question 4 – Heat Transfer Through a Steel Tube (12 points)

A steel cylindrical tube has an internal diameter of 5 cm and external diameter of 7.6 cm. The external surface is covered with two insultation layers, each of thickness 2 cm. The thermal conductivity of steel is k = 15 W/m·°C, the thermal conductivity of the first insulation material is k = 0.1 W/m·°C and the thermal conductivity of the second insulation material is k = 0.05 W/m·°C.

A hot gas at 330°C with a heat transfer coefficient h = 400 $W/m^2·°C$ flows inside the tube. The outer surface of the insulation is exposed to cooler air at 30°C with h = 60 $W/m^2·°C$.

a) Draw a scheme of the tube and the corresponding thermal resistance circuit.

b) Calculate the heat flow rate from the tube to the air for 10 m length of the tube.

c) Calculate the temperatures at all interfaces in the system.

d) Do you think that the second insulating layer is useful or not? Justify your answer.